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Taxonomic Studies on the Genus *Apophylia* from Taiwan (Coleoptera: Chrysomelidae: Galerucinae)

Chi-Feng Lee[1,*] and Jan Bezděk[2]

Abstract

Lee, C. F. and J. Bezděk. 2014. Taxonomic Studies on the Genus *Apophylia* from Taiwan (Coleoptera: Chrysomelidae: Galerucinae). J. Taiwan Agric. Res. 63(1):1–16.

The Taiwanese species of *Apophylia* Thomson are reviewed. Four species are redescribed: *A. asahinai* Chûjô, 1962; *A. beeneni* Bezděk, 2003; *A. miyamotoi* Kimoto, 1969; and *A. velai* Bezděk, 2003. Two new synonyms are proposed: *A. taiwanica* Bezděk, 2003 as a junior synonym of *A. asahinai* Chûjô, 1962; and *A. kaoi* Bezděk and Lee, 2009 as a junior synonym of *A. velai* Bezděk, 2003. Diagnostic characters of both sexes are illustrated. Occurrence of sibling species of chrysomelids in Taiwan is briefly discussed.

Key words: Leaf beetles, Taxonomy, Endophallic sclerites.

INTRODUCTION

Chrysomelidae is one of the most diverse family belonging to Coleoptera. The genus *Apophylia* Thomson, 1858 is a large genus of the subfamily Galerucinae, which comparised 144 species distributed in Asia and Africa (Wilcox 1971; Beenen 2010; Bezděk unpublished data). The biology is little known, only adults were collected on Poaceae, Ehretiaceae, Lamiaceae, Convolulaceae, and Acanthaceae (Jolivet & Hawkeswood 1995). Recently Bezděk (2007) reported that two species of this genus were collected by sweeping of Cynoglossum sp. (Boraginaceae). No articles reported that adults of *Apophylia* caused damage to crops.

The taxonomic history of *Apophylia* in Taiwan is scattered and complex. *A. flavovirens* Fairmaire, 1878 and *A. nigriceps* Laboissière, 1927 were first recorded by Chûjô (1935). Later, Chûjô (1962) reported again on *A. nigriceps* and described the new species *A. asahinai*. *A. flavovirens* was recorded again from Taiwan by Kimoto (1965), and a new species, *A. miyamotoi* Kimoto, was described. However, after examining types Bezděk (2003a) found that *A. flavovirens* and *A. nigriceps* identified by Kimoto and Chûjô, respectively, were misidentified and described them as new species, *A. beeneni* and *A. velai*. Bezděk (2003b) also illustrated the male aedeagus of *A. asahinai* and described a new species, *A. taiwanica*. This species and *A. asahinai* are morphologically indistinguishable. Bezděk and Lee (2009) described the sixth new species although it and *A. velai* were also morphologically indistinguishable.

The Taiwan Chrysomelid Research Team (TCRT) was founded in 2005 and composed of 10 members. All of them are amateurs who are interested in inventorying all species of Chryso-

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melidae in Taiwan. Specimens of the genus have been extensively collected and studied, and plants that adults feed on recorded. The diagnostic characters were assessed and the status of all species was evaluated based on a large series of specimens, and the results are reported here. In addition, the possibility of sibling species of *Apophylia* in Taiwan is discussed based on their distributions and biology.

MATERIALS AND METHODS

Nearly 500 specimens have been examined. About half were collected by TCRT and deposited at the Taiwan Agricultural Research Institute (TARI). The others are conserved in the historical collection compartments at TARI. To prepare drawings of the adult reproductive systems, the abdomens of adults were separated and boiled in a 10% KOH solution, cleared in distilled water, and then covered by a cover glass on slide glass with glycerin for observation. Specimens were examined and drawings were made using a Leica M165 stereomicroscope. Microscopic slides were examined and illustrated using a Nikon ECLIPSE 50i microscope. Body parts were then stored in glycerin tubes with the dry mounted specimens.

Host plants are recorded by observing adult feeding behavior in the field. These plants were identified by Chih-Kai Yang.

The type specimens examined are deposited in the following collections: JBCB (Jan Bezděk collection, Brno, Czech Republic), KUEC (Kyushu University, Fukuoka, Japan), and TARI (Taiwan Agricultural Research Institute, Taichung, Taiwan).

Exact label data are cited for all type specimens; a double slash (//) divides the data on different labels and a single slash (/) divides the data in different rows. Other comments and remarks are indicated as follow: (p) - preceding data are printed, (h)- preceding data are handwritten, (w)- white label, (y)- yellow label, and (r)- red label.

RESULTS AND DISCUSSION

Genus *Apophylia* Thomson, 1858

Apophylia Thomson, 1858: 221. Type species: *Apophylia chloroptera* Thomson, 1858.

Bequaertinia Laboissière, 1922: 263. Type species: *Bequaertinia nodicornis* Laboissière, 1922.

Galerucesthis Weise, 1896: 296. Type species: *Auchenia thalassina* Faldermann, 1835.

Glyptolus Jacoby, 1884: 62. Type species: *Glyptolus viridis* Jacoby, 1884.

Malaxia Fairmaire, 1878: 139. Type species: *Malaxia flavovirens* Fairmaire, 1878.

Malaxoides Fairmaire, 1888: 155. Type species: *Malaxoides grandicornis* Fairmaire, 1888.

Daignosis. Body small to medium size, elongate. Color variable but elytra metallic green. Body covered with dense pubescence.

Head hypo-prognathous, oval, convex from lateral view. Frons without frontal ridge. Annal calli smooth or raised, separated from each other, not delineated from vertex. Interantennal space narrower than transverse diameter of eye. Clypeus short, labrum typical. Antenna 11-segmented, filiform.

Pronotum wide, widest near apex, with lateral impressions. All borders unmargined. Procoxal cavity open behind. Primary setigerous pore on anterior part of lateral margin of pronotum.

Elytra elongate, with lateral sides parallel. Humeral callus well developed, without shallow transverse impression posteriorly. Elytral punctures, small but distinct, extremely dense. Epipleuron wide, almost reaching elytral apex.

Apices of tibiae unspined. First segment of posterior tarsus as long as remainder combined. Tarsal claws simple, with angular bases.

***Apophylia asahinai* Chûjô, 1962**

Apophylia flavovirens: Chûjô, 1935: 174 (Taihorin and Taihorinsho = Talin, in Chiyi; Sokutsu, near Chiasien, in Kaohsiung;

Fuhosho, a unidentified locality of Chishan, in Kaohsiung; Shis = Shishitou, in Nantou); Chûjô, 1938: 135.

Apophylia asahinai Chûjô, 1962: 23 (Musya = Wushe, in Nantou); Chûjô, 1963: 387 (Takao = Kaohsiung city; Kosempo = Chiasien, in Kaohsiung); Kimoto, 1965: 489; Kimoto, 1966: 26 (Polisha = Puli, in Nantou; Zentai = Chietapu, in Tainan); Kimoto, 1969: 22 (Fenchihu, in Chiayi); Kimoto, 1986: 56 (Nanshanchi, in Nantou; Lushan, in Nantou); Kimoto, 1991: 9 (Hohuanshan-doubtful locality, in Nantou; Shaping, in Kaohsiung); Bezděk, 2003b: 481 (illustration of male aedeagus; Tungpu, in Nantou).

Apophylia taiwanica Bezděk, 2003b: 505 (Lienhuachih, in Nantou; Alishan, in Chiayi). **new synonymy**

Type Specimens Examined. *Apophylia asahinai*: Holotype (♂), labelled: "Musha (h) FORMOSA (p) 26.X.1928 (h) COL. M. CHUJO (w, p) //Holotype (r, h) //*Apophylia asahinai* CHÛJÔ (w, h)" (KUEC).

Apophylia taiwanica: 1 paratype (♂), labelled: "Taihorin/Formosa/H. Sauter, 1911 (w, p) //7.VII. (w, p) //Chujo det. (w, h) //PARATYPUS/*Apophylia*/taiwanica sp. nov./J. Bezděk det. 2002 (r, p)" (JBCB); 1 paratype (♂), with same labels but collected "7.XI." (JBCB); 1 paratype (♂), labelled: "Formosa/Taihorin. (p) VI. (h) 09/Sauter S G. (y, p) //PARATYPUS/*Apophylia*/taiwanica sp. nov./J. Bezděk det. 2002 (r, p)" (JBCB).

Specimens Examined (n = 137). **Hsinchu:** 1♂, Peitelaman, 26.VI.2008, leg. H. Lee; 1♂. Wufeng, 14–16.VII.1982, leg. K. C. Chou and C. C. Pan; **Ilan:** 1♀, Fushan botanical park, 8.V.2008, leg. S. F. Yu; **Keelung:** 1♀, Chingjenhu, 9.IV.2009, leg. S. Y. Wu; 1♂, same locality, 10–13.X.2012, leg. L. P. Hsu; **Kaohsiung:** 1♂, Chiasien, 10–13.V.1981, leg. C. C. Chen and C. C. Pan; 1♀, Chungchihkuan, 3.VII.2009, leg. M. H. Tsou; 1♂, 1♀, same locality, 10–13.X.2012, leg. L. P. Hsu; 5♂♂, 1♀, Tengchih, 4.VIII.2012, leg. J. C. Chen; **Nantou:** 1♀, Hoshe, 22.VII.1982, L. Y. Chou and T. Lin; 1♀, Lushan, 27–31.V.1980, leg. K. S. Lin and L. Y. Chou; 1♀, Meifeng, 19.VI.2010, leg. C. F. Lee; 1♀, Sunglintsun, 9.VII.2007, leg. M. H. Tsou; 4♂♂, Tungpu, 20–22.VI.1980, leg. C. C. Chen; 3♂♂, 2♀♀, same locality, 25–29.IX.1980, leg. L. Y. Chou and T. Lin; 2♀♀, 28.IV.–2.V.1981, leg. T. Lin and C. J. Lee; 2♂♂, 3♀♀, same locality, 19–23.VII.1982, leg. L. Y. Chou and T. Lin; 1♀, same locality, 22–25.XI.1982, leg. K. C. Chou and S. P. Huang; 2♂♂, same locality, 20–24.VI.1983, leg. K. C. Chou and C. Y. Wong; 3♂♂, 1♀, same locality, 23–27.VII.1984, leg. K. C. Chou and C. H. Yang; 2♂♂, 2♀♀, same locality, 5–8.X.1981, leg. T. Lin and W. S. Tang; 1♂, Wushe, 30.VIII.–2.IX.1982, leg. L. Y. Chou and K. C. Chou; 1♂, same locality, 7–8.X.1982, leg. K. C. Chou; 4♂♂, Wutakeng, 5.V.2013, leg. J. C. Chen; **Pingtung:** 1♀, Mutan, 5.V.2010, leg. J. C. Chen; 1♀, Nanjenshan, 7.XII.2009, leg. Y. T. Wang; 3♂♂, 4♀♀, Peihulushan, 4.XI.2009, leg. M. H. Tsou; 1♀, Peitawushan, 21.VII.2010, leg. J. C. Chen; 1♂, same locality, 25.VI.2012, leg. J. C. Chen; 1♂, Tahanshan, 1.VIII.2011, leg. J. C. Chen; 1♂, same locality, 12.IX.2011, leg. J. C. Chen; 2♂♂, 3♀♀, same locality, 6.VI.2012, leg. C. F. Lee; 4♂♂, same locality, 19.VII.2012, leg. C. F. Lee; 1♀, same locality, 20.VIII.2012, leg. J. C. Chen; 1♀, same locality, 14.IX.2012, leg. Y T. Chung; 2♂♂, same locality, 25.V.2013, leg. Y. T. Chung; 1♂, Wanan Trail, 31.VIII.2009, leg. J. C. Chen; **Tainan:** 1♂, Pichien trail, 31.III.2010, leg. U. Ong; **Taipei:** 1♀, Chutzuhu, 26.V.1983, leg. K.C. Chou; 4♂♂, 9♀♀, same locality, 9.VIII. 2008, leg. M. H. Tsou; 1♀, Fengkueitsui, 29.VI.2007, leg. S. F. Yu; 1♀, Fulung, 20.V.2008, leg. H. Lee; 1♂,

1♀, Hsiaoyukeng, 22.VI.2008, leg. S. F. Yu; 1♂, Tatunshan, 20.VI.2010, leg. M. H. Tsou; 4♂♂, Wulai, 22.X.2006, leg. S. F. Yu; 4♂♂, Yuanshan, 11.V.2012, leg. S. F. Yu; **Taitung:** 1♀, Chihpen, 17–18. II. 1983, leg. L.Y. Chou and K.C. Chou; 1♀, same locality, 15.XI.2007, leg. I. C. Yu; 1♀, Lichia trail, 6.IV.2010, leg. J. C. Chen; 1♀, Motien, 23.V.2011, leg. C. F. Lee; 1♀, Tajen, 25.II.2009, leg. C. F. Lee; 1♀, Wulu, 7.VII.2010, leg. J. C. Chen; **Taoyuan:** 1♂, 1♀, Fuhsing, 6.V.1983, leg. K. C. Chou and C. C. Pan; 4♂♂, 2♀♀, Lalashan, 15.VII.2009, leg. H. J. Chen; 1♀, Paling, 3–5.V.1983, leg. K.C. Chou and C.C. Pan; 1♂, 1♀, same locality, 23.V.2009, leg. M. H. Tsou; 1♂, same locality, 1.IX.2009, leg. H. Lee; 1♀, Tungyanshan, 26.IV.2007, leg. H. Lee; 12♂♂, same locality, 12.IV.2010, leg. H. Lee.

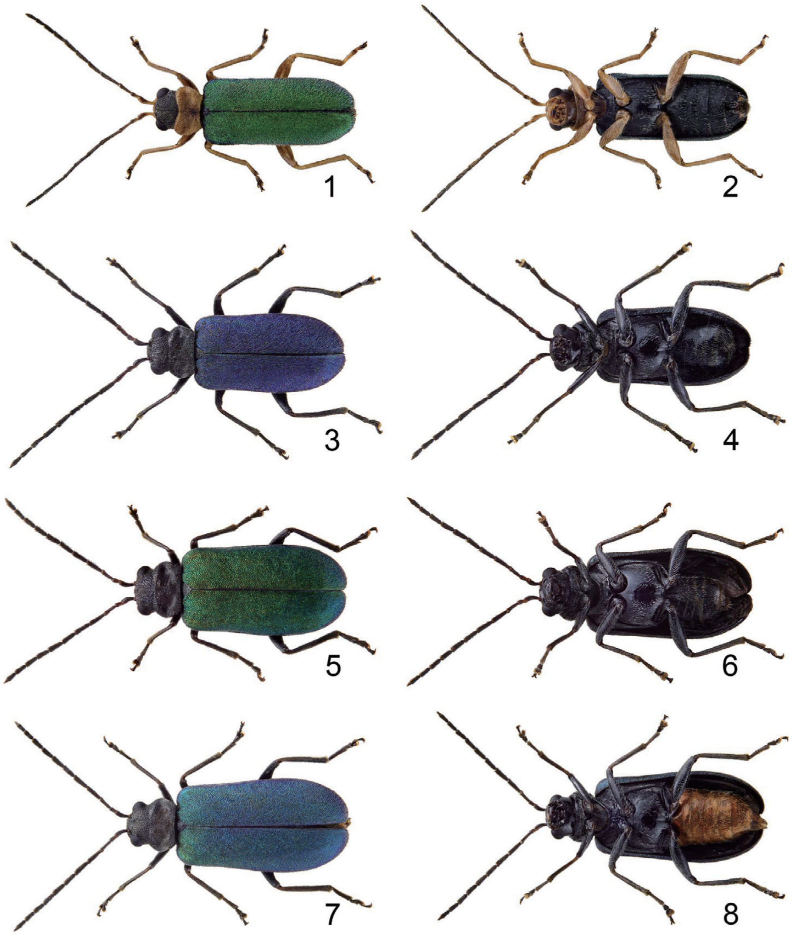
Remarks. *Apophylia asahinai* is similar to *A. beeneni* with yellow mouthparts and legs but may be distinguished from the latter by the yellow pronotum with black spots (in contrast with the blackish brown pronotum with yellow anterior and posterior margins in *A. beeneni*).

Male. Length 5.5–6.6 mm. General color (Figs. 1–2) black; head bicolorous, vertex, frontal tubercles and postgena black, anterior part of head, mouthparts and underside yellow; antenna yellowish brown but last three or five antennomeres darkened; prothorax yellow, pronotum with median black spot, sometimes with one pair of small black spots at sides, in some specimens black spots absent; elytra metallic green; legs yellow. Antennomeres (= antennal segments) VII-XI flattened and widened, ratio of length of antennomeres III to XI about 1.0 : 1.6 : 1.3 : 1.2 : 1.2 : 1.1 : 0.9 : 0.8 : 1.0; ratio of length to width of antennomeres III to XI about 3.2 : 5.2 : 4.2 : 4.0 : 3.6 : 3.1 : 2.4 : 2.4 : 3.0 (Fig. 9). Penis (Fig. 11a) slender, 5.8 times longer than wide; parallel-sided, apex narrowly rounded, or abruptly narrowed subapically in some specimens, moderately curved near base from lateral view (Fig. 12); opening apically tapering, basal margin indistinct; endophallic sclerites composed of three visible sclerites, stick-like (elongate, parallel-sided) sclerite longest, about 0.7 times as length of penis; a small, elongate, flattened sclerite located near apex of stick-like sclerite, outer margin of apex with small teeth; a small, flattened, curved, sclerite behind base of stick-like sclerite.

Female. Length 7.4–8.1 mm. Similar to male, but antennomeres VII to XI a little widened, ratio of length of antennomeres III to XI about 1.0 : 1.3 : 1.2 : 1.1 : 1.1 : 1.0 : 1.0 : 0.8 : 1.1; ratio of length to width of antennomeres III to XI about 3.4 : 4.5 : 3.9 : 3.6 : 3.1 : 3.0 : 3.0 : 2.5 : 3.5 (Fig. 10). Apex of last abdominal ventrite with a shallow median notch. Gonocoxae (Fig. 14) wide, apex of each gonocoxa with seven to nine setae, connection of gonocoxae extremely slender, base widened. Sternite VIII (Fig. 13) weakly sclerotized, apical margin convex at middle, surface with sparse short setae along apical margin, spiculum extremely long. Spermathecal receptaculum (Fig. 15) strongly swollen; pump longer, moderately curved; spermathecal duct short, stout, shallowly projecting into receptaculum.

Host Plants. Boraginaceae: *Ehretia resinosa* Hance; *E. dicksonii* Hance.; *E. acuminate* R. Brown; *E. longiflora* Champ. ex Benth.

Notes. *Apophylia taiwanica* was described based on the specimens with a narrow apex of penis (Fig. 11b) (Bezděk 2003b) in contrast to the wider apex of aedeagus in *A. asahinai*. After the description of *Apophylia taiwanica*, the second author (J. B.) had the opportunity to identify specimens with transitional forms of the aedeagus. Now, after the examination of more than 100 specimens, we can confirm that the apex of



Figs. 1–8. Color habitus of *Apophylia* species. 1. *A. asahinai*, male, dorsal view; 2. *A. asahinai*, male, ventral view; 3. *A. miyamotoi*, male, dorsal view; 4. *A. miyamotoi*, male, ventral view; 5. *A. miyamotoi*, female, dorsal view; 6. *A. miyamotoi*, female, ventral view; 7. *A. miyamotoi*, female, dorsal view, color variation; 8. *A. miyamotoi*, female, ventral view, color variation.

the aedeagus varies from narrow to wide (Figs. 11a, b). Thus, *A. taiwanica* is proposed to be a new synonym of *A. asahinai*.

Distribution. Taiwan. It is a common and widespread species in Taiwan (Fig. 16). Most populations inhabit lower elevation habitats (0–1,500 m).

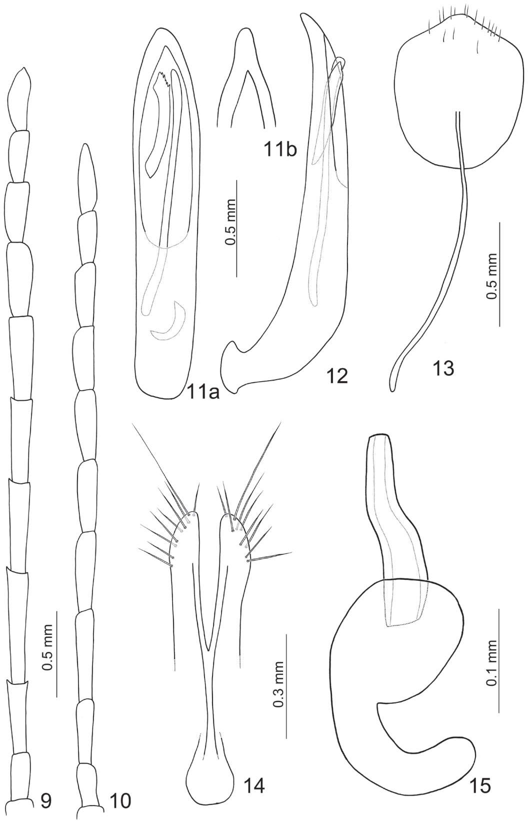
Apophylia beeneni **Bezděk, 2003**

Apophylia flavovirens: Kimoto, 1965: 489 (Yentempo = Yentenchi, in Kaohsiung); Kimoto, 1966: 27 (Zentai = Chietapu, in Tainan); Kimoto, 1969: 23; Kimoto, 1987: 188.

Apophylia beeneni Bezděk, 2003a: 207 (Sokutsu, near Chiasien, in Kaohsiung).

Type Specimens Examined. 2 paratypes (♀♀), labelled: “FORMOSA/KENTING/3-10.6.1995/DALIHOD leg. (w, p) // PARATYPUS/*Apophylia*/beeneni sp. nov./J. Bezděk det. 2002 (r, p)” (JBCB).

Specimens Examined (n = 48). **Pingtung:** 1♂, 2♀♀, Checheng, 5.XII.2011, leg. J. C. Chen; 1♂, 1♀, Hengchun, 7.VII.2010, leg. J. C. Chen; 1♂, 1♀, Kenting, 2–6. III.1982, leg. K. C. Chou and C. N. Lin; 1♂, Mutan, 28.V.2010, leg. J. C. Chen;

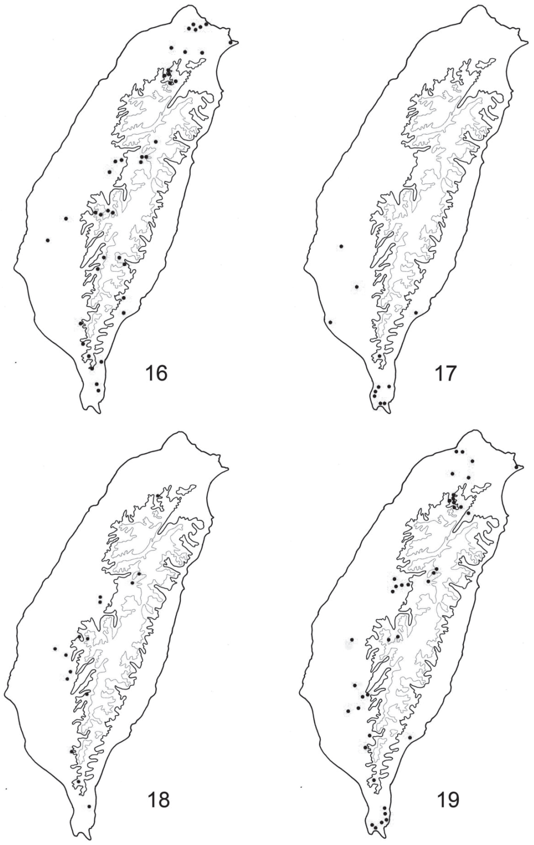


Figs. 9–15. *Apophylia asahinai*. 9. Antenna, male; 10. Antenna, female; 11a. Penis, dorsal view; b. Apex of penis, dorsal view, variation; 12. Penis, lateral view; 13. Sternite VIII; 14. Gonocoxae; 15. Spermatheca.

1♀, Sheting, 4.XI.2009, leg. M. H. Tsou; 9♂♂. 4♀♀, same locality, 7.VII.2010, leg. J. C. Chen; 6♂♂, Suchunghsi, 8.V.2013, leg. Y. T. Chung; 8♂♂, 1♀, Tahanshan, 24.VI.2007, leg. C. F. Lee; 2♂♂, 2♀♀, same locality, 17.VII.2007, leg. M. H. Tsou; 1♂, 1♀, same locality, 8.X.2012, leg. S. F. Yu; 1♂, 1♀, same locality, 3.VI.2013, leg. J. C. Chen; **Taitung:** 3♀♀, Chihpen, 15.XI.2007, leg. Y. C. Yu.

Remarks. This species is similar to *A. asahinai* with yellow mouthparts and legs. Besides differences mentioned in the diagnosis of *A. asahinai*, *A. beeneni* has a smaller body, darkened labrum, and modified metasternum in males.

Male. Length 5.1 mm. General color (Figs. 20–21) black; head bicolorous, vertex, frontal tubercles and postgena black, anterior part of head, mouthparts yellow except labrum blackish brown; antenna yellowish brown but last three or five antennomeres darkened; prothorax yellow, pronotum blackish brown but anterior and posterior margins yellow; elytra metallic green; legs yellow. Antennomeres VII-XI filiform, ratio of length of antennomeres III to XI about 1.0 : 1.3 : 1.3 : 1.2 : 1.1 : 0.9 : 0.9 : 0.9 : 1.1; ratio of length to width of antennomeres III to XI about 4.2 : 5.5 : 6.0 : 5.6 : 5.2 : 4.3 : 3.8 : 3.6 : 5.0 (Fig. 28). Penis (Fig. 30) slender, 5.3 times longer than wide; parallel-sided, apex narrowly rounded, strongly and subapically curved and basally widened in lateral view (Fig. 31); apical margin of



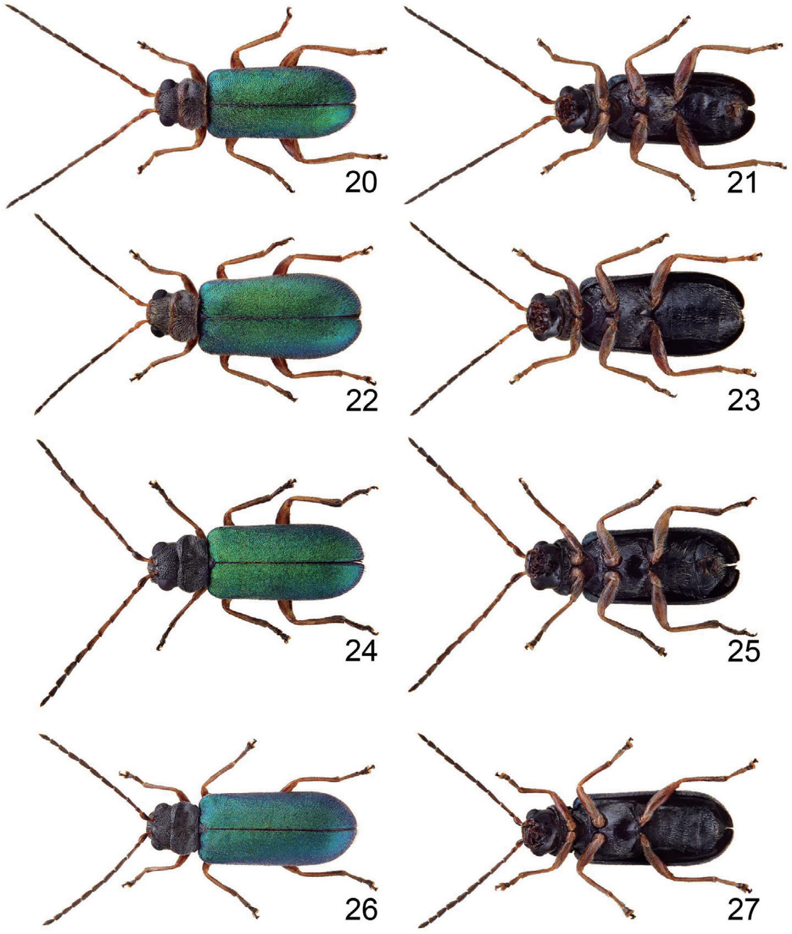
Figs. 16–19. Distribution map of *Apophylia* species, solid line: 1,000 m, broken line: 2,000 m. 16. *A. asahinai*; 17. *A. beeneni*; 18. *A. miyamotoi*; 19. *A. velai*.

opening indistinct; endophallic sclerites composed of two visible sclerites, stick-like sclerite short, about 0.3 times as length of penis; another sclerite as long as stick-like sclerite, but apically widened and flattened, outer margin of apex serrate.

Female. Length 5.8–6.5 mm. Similar to male (Figs. 22–23), but antennomeres VII to XI shorter and wider, ratio of length of antennomeres III to XI about 1.0 : 1.2 : 1.2 : 1.1 : 1.1 : 1.0 : 1.0 : 0.8 : 1.0; ratio of length to width of antennomeres III to XI about 3.2 : 4.3 : 4.3 : 3.9 : 3.7 : 3.6 : 3.8 : 3.5 : 4.3 (Fig. 29). Apex of last abdominal ventrite rounded. Gonocoxae (Fig. 33) wide, apex of each gonocoxa with eight setae, connection of gonocoxae slender, base slightly widened. Sternite VIII (Fig. 32) weakly sclerotized, apical margin convex at middle, surface with sparse short setae at sides and along apical margin, spiculum relatively shorter. Spermathecal receptaculum (Fig. 34) strongly swollen; pump longer, moderately curved; spermathecal duct short, stout, shallowly projecting into receptaculum.

Host Plants. Boraginaceae: *Trichodesma calycosum* Collett & Hemsl.; *Carmona retusa* (Vahl) Masam.; *Ehretia resinosa* Hance.

Distribution. Taiwan, Korea, Vietnam, Hongkong, China (Beijin, Fujian, Guangxi, Hainan, Heilongjiang, Sichuan, and Zhejiang). This species is restricted to southern Taiwan (Fig. 17).



Figs. 20–27. Color habitus of *Apophylia* species. 20. *A. beeneni*, male, dorsal view; 21. *A. beeneni*, male, ventral view; 22. *A. beeneni*, female, dorsal view; 23. *A. beeneni*, female, ventral view; 24. *A. velai*, male, dorsal view; 25. *A. velai*, male, ventral view; 26. *A. velai*, female, dorsal view; 27. *A. velai*, female, ventral view.

***Apophylia miyamotoi* Kimoto, 1969**

Apophylia miyamotoi Kimoto, 1969: 23 (Fenchihu, in Chiayi; Chiaoliping, in Chiayi); Kimoto, 1986: 56 (Jiuyuehtan, in Nantou); Kimoto, 1987: 188 (Sungkang, in Nantou); Kimoto, 1989: 248 (Chunyunshan, in Kaohsiung); Kimoto, 1991: 9 (Liukui, in Kaoshiung); Bezděk, 2003a: 202 (illustration of male aedeagus).

Type Specimens Examined. Holotype (♂), labelled: "(Taiwan) Fenchihu (p) 1,400 m (h) Chiayi Hsien (w, p) //10.IV. (h) 1965 S. Miyamoto (w, p) //Japan-U.S. Co-op. Sci. Programme (y, p) //HOLOTYPE (r, p) // *Apophylia miyamotoi* Kimoto, n.sp. (w, h)" (KUEC).

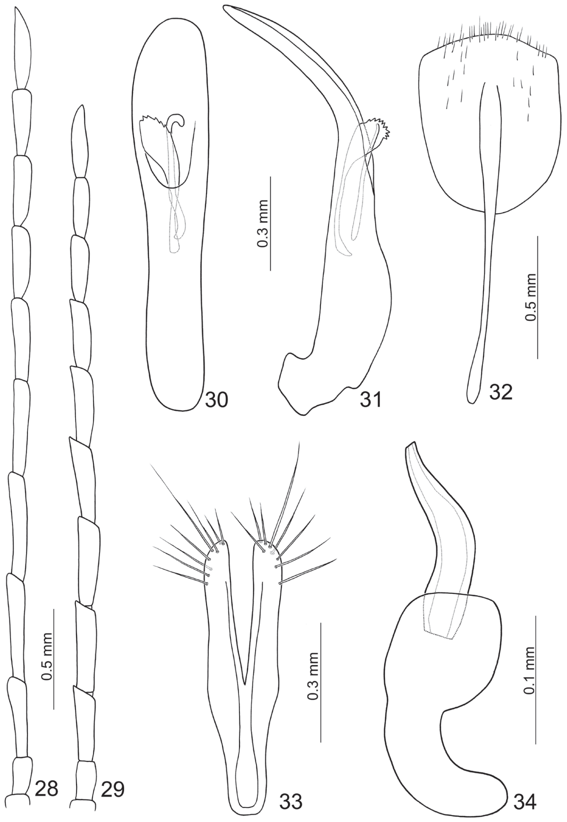
Specimens Examined (n = 36). **Kaohsiung:** 1♀, Tengchih, 18.IV.2013, leg. B. X. Guo; **Nantou:** 2♂♂, Lienhuachih, 27.III.2008, leg. C. F. Lee; 1♂, Wushe, 19–22.IV.1983, leg. K. C. Chou and P. Huang; **Pingtung:** 1♂, Mutan, 19.II.2007, leg. S. F. Yu; 4♀♀, Peitawushan, 10.V. 2010, leg. J. C. Chen; 2♂♂, 2♀♀, same locality, 12.IV.2013, leg. Y. T. Chung; 1♀, Tahanshan, 9.IV.2010, leg. J. C. Chen; 1♀, same locality, 10.IV.2010, U. Ong; 1♂, 1♀, same locality, 28.IV.2012, leg.

M. H. Tsou; **Tainan:** 1♂, 1♀, Meiling, 24.IV.2013, leg. B. X. Guo; 8♂♂, 2♀♀, Pichien trail, 31.III.2010, leg. U. Ong; 2♂♂, same locality, 22.III.2011, leg. U. Ong; **Taoyuan:** 4♂♂, 1♀, Tungyanshan, 12.IV.2010, leg. H. Lee.

Remarks. *Apophylia miyamotoi* is characterized by its black body.

Male. Length 4.7–5.9 mm. General color (Figs. 3–4) black but tibia paler; elytra metallic green or blue. Antennomeres VII–XI flattened and widened, ratio of length of antennomeres III to XI about 1.0 : 1.3 : 1.3 : 1.2 : 1.2 : 1.1 : 1.1 : 0.9 : 1.1; ratio of length to width of antennomeres III to XI about 3.2 : 4.0 : 4.0 : 3.8 : 3.8 : 3.7 : 3.7 : 3.2 : 3.9 (Fig. 35). Penis (Fig. 37) extremely elongate, 7.3 times longer than wide; sides asymmetric, right lateral margin widened at apical 2/5; apex narrowly rounded and posteriorly curved, moderately curved near base from lateral view (Fig. 38); opening apically tapering, basal margin indistinct; endophallic sclerites composed of two visible sclerites, stick-like sclerite longest, about 0.5 times as length of penis; another with apex strongly widened and flattened, margin with large teeth, smaller, about 0.8 times length of stick-like sclerite.

Female. Length 7.4–8.1 mm. Similar to male (Figs. 5–8), but abdomen brown or yellowish brown; antenna filiform, ratio of length of antennomeres III to XI about 1.0 : 1.4 : 1.4 : 1.2 : 1.2 : 1.2 : 1.0 : 1.0 : 1.1; ratio of length to width of antennomeres



Figs. 28–34. *Apophylia beeneni*. 28. Antenna, male; 29. Antenna, female; 30. Penis, dorsal view; 31. Penis, lateral view; 32. Sternite VIII; 33. Gonocoxae; 34. Spermatheca.

III to XI about 3.2 : 4.5 : 4.5 : 4.0 : 3.5 : 3.5 : 2.9 : 3.2 : 3.1 (Fig. 36). Apex of last abdominal ventrite rounded. Gonocoxae (Fig. 40) wide, apex of each gonocoxa with seven to eight setae, connection of gonocoxae extremely slender, base widened. Sternite VIII (Fig. 39) weakly sclerotized, surface with dense long setae at sides and along apical margin, spiculum extremely long. Spermathecal receptaculum (Fig. 41) strongly swollen; pump longer, moderately curved; spermathecal duct long, stout, shallowly projecting into receptaculum.

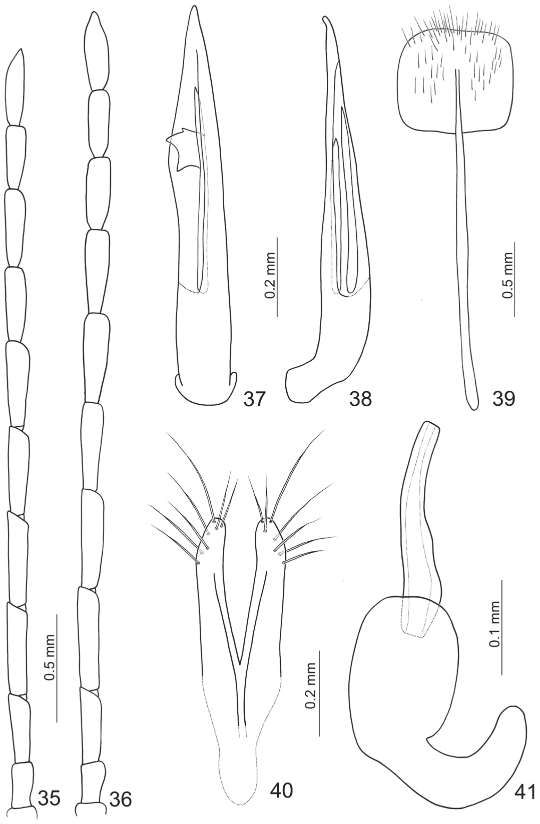
Host Plants. Boraginaceae: *Ehretia longiflora* Champ. ex Benth.; *E. acuminate* R. Brown.

Distribution. Taiwan. Specimens are uncommon but the species is widespread in Taiwan (Fig. 18). Most populations inhabit low elevation habitats (0–1,500 m).

***Apophylia velai* Bezděk, 2003**

Apophylia nigripes (sic!): Chûjô, 1935: 174 [Pingtung: Henchun (= Kankau); Manchoutsun (= Teraso)]; Chûjô, 1938: 135.

Apophylia nigriceps: Chûjô, 1962: 21 (Taihoku = Taipei city); Chûjô, 1963: 388 (Kosempo = Chiasien, in Kaohsiung); Kimoto, 1965: 489; Kimoto, 1966: 27; Kimoto, 1969: 23 (Nanshanchi, in Nantou; Meichi, in Nantou; Kenting, in Pingtung); Kimoto, 1986: 56 (Jiuyehtan, in Nantou); Kimoto, 1987: 188 (Sungkang, in Nantou); Kimoto, 1989: 248 (Chunyunshan, in Kaohsiung); Kimoto, 1991: 8 (Shaping and Shinanshan, in Kaohsiung).



Figs. 35–41. *Apophylia miyamotoi*. 35. Antenna, male; 36. Antenna, female; 37. Penis, dorsal view; 38. Penis, lateral view; 39. Sternite VIII; 40. Gonocoxae; 41. Spermatheca.

Apophylia velai Bezděk, 2003a: 222 (Taihorin = Talin, in Chiayi; Chilan, in Ilan; Huisun, in Nantou; Guanyinshan, in Taipei).

Apophylia kaoi Bezděk and Lee, 2009: 430 (Chuwei, in Taipei). **new synonymy**

Type Specimens Examined. *Apophylia velai*: 1 paratype (♂), labelled: "Kankau (Koshun) /Formosa/H. Sauter V. 1912 (w, p) //7.IV. (w, p) //Chujo det. (w, h) // PARATYPUS/*Apophylia*/velai sp. nov./J. Bezděk det. 2002 (r, p)" (JBCB); 1 paratype (♂), labelled: "Teraso II. 09 (w, h) // Chujo det. (w, h) //PARATYPUS/*Apophylia*/velai sp. nov./J. Bezděk det. 2002 (r, p)" (JBCB).

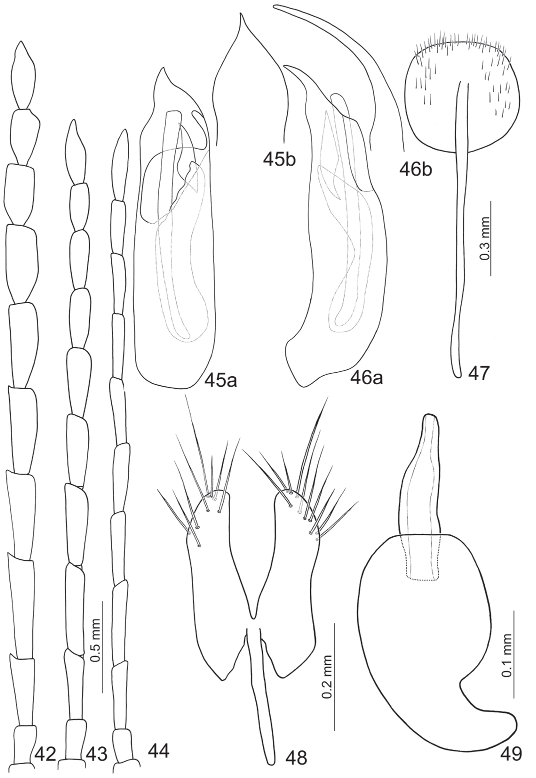
Apophylia kaoi: Holotype (♂), labelled: "Taiwan: Taipei (1181) /Fushan/05.IV.2007, leg. M.-H. Tsao (w, p) //HOLOTYPUS, /*Apophylia*/ kaoi sp. nov., /Bezděk & Lee det. 2009 (r, p)" (TARI); 1 paratype (♂), labelled: "Taiwan: Taipei (1182) /Fushan/05.IV.2007, leg. M.-H. Tsao (w, p) //PARATYPUS, /*Apophylia*/kaoi sp. nov., /Bezděk & Lee det. 2009 (r, p)" (JBCB).

Specimens Examined (n = 270). **Hsinchu:** 1♀, Peitelaman, 26.VI.2008, leg. S. F. Yu; **Kaohsiung:** 4♂♂, 3♀♀, Meinung, 25.IV.2012, leg. leg. J. C. Chen; **Nantou:** 1♀, Meifeng, 7–9.V.1981, leg. K. S. Lin and S. C. Lin; 1♂, same locality, 20.IV.2011, leg. C. F. Lee; 1♂, Tatachia, 27.IV.2010, leg. C. F. Lee; 4♀♀, Tungpu, 20–22.VI.1980, leg. C. C. Chen; 3♂♂, same locality, 28.IV.–2.V.1981, leg. T. Lin and C. J. Lee; 1♀, same locality, 5–8. X.1981, leg. T. Lin and W. S. Tang; 4♂♂, 14♀♀, same locality, 19–23.VII.1982, leg. L. Y. Chou and T. Lin; 4♂♂, 13♀♀, same locality, 20–24.VI.1983, leg. K. C. Chou and C. Y. Wang; 24♂♂, 3♀♀, same locality, 16–20.IV.1984, leg. K. C. Chou and C. H. Yang; 29♀♀, same locality, 23–27. VII.1984, leg. K. C. Chou & C. H. Yang; 1♂, Wanta Reservoir, 24.IV.2008, leg. W. T. Liu; 5♂♂, 2♀♀, Wushe, 6–11.V.1981, K. S. Lin and S. C. Lin; 1♀, same locality, 23–28.VI.1981, leg. K. S. Lin and W. S. Tang; 2♂♂, same locality, 19–22.IV.1983, leg. K. C. Chou and P. Huang; 3♀♀, same locality, 7.V.1984, leg. K. C. Chou and C. C. Pan; 1♂, 1♀, Wutakeng, 5.V.2013, leg. J. C. Chen; 1♀, Yushih, 4.VIII.1981, leg. T. Lin and W. S. Tang; **Pingtung:** 2♀♀, Chiupeng, 6–27.II.2010, leg. M. L. Jeng; 4♀♀, Kenting, 422.III.1980, leg. K. S. Lin; 1♂, same locality, 18–23.III.1981, leg. K. S. Lin and T. Lin; 8♂♂, 16♀♀, same locality, 24–28.VI.1981, leg. T. Lin and C. C. Pan; 13♂♂, 14♀♀, same locality, 22–26.III.1982, leg. T. Lin and S. C. Lin; 1♂, 1♀, same locality, 15.III.1984, leg. K. C. Chou and C. C. Pan; 5♂♂, Nanjenhu, 15.III.2010, leg. M. H. Tshou; 1♀, Neiwen, 12.IV.2013, leg. B. X. Guo; 1♀, Peitawushan, 10.V.2010, leg. J. C. Chen; 1♀, Shantimen, 24.III.1982, leg. K. C. Chou and C. C. Pan; 1♀, Shouka, 16.IV.2013, leg. Y. T. Chung; 1♀, Tahanshan, 20.VII.2007, leg. M. H. Tsou; 1♂, same locality, 14.VIII.2011, leg. Y. T. Wang; 1♂, 1♂, same locality, 6.VI.2012, leg. C. F. Lee; 1♂, same locality, 18.VI.2012, leg. Y. T. Chung; **Taipei:** 3♀♀, Chuwei, V.2006, leg. H. T. Cheng; 1♀, same locality, IV.2007, leg. H. T. Cheng; 3♀♀, Fulung, 20.V.2008, leg. H. Lee; 1♂, Fushan, 10.IV.2010, leg. H. J. Chen; 1♀, Sushoushan, 2.V.2008, leg. H. J. Chen; 1♀, Wulai, 20.IV.2007, leg. H. J. Chen; 2♀♀, Yuanshan, 11.V.2012, leg. S. F. Yu; **Taitung:** 2♂♂, 5♀♀, Chihpen, 24.V.2013, leg. J. C. Chen; **Taoyuan:** 2♂♂, 1♀, Fuhsing, 6.V.1983, leg. K. C. Chou and C. C. Pan; 11♂♂, 9♀♀, Lalashan, 2.V.2009, leg. M. H. Tsou; 1♀, Lofu, 11.IV.2010, leg. M. H. Tsou; 1♀, same locality, 19.VI.2010, leg. H. J. Chen; 4♀♀, Paling, 3–5.V.1983, leg. K. C. Chou and C. C. Pan; 2♂♂, Tungyanshan, 12.IV.2010, leg. H. Lee.

Remarks. *Apophylia velai* is similar to *A. miyamotoi* with black head and pronotum, but differs in possessing yellow legs.

Male. Length 4.9–5.9 mm. General color (Figs. 24–25) black; antenna yellowish brown but last three or five antennomeres darkened; elytra metallic green; legs yellow but base of femur, apex of tibia, and tarsi darkened. Antennomeres III–XI flattened and widened, ratio of length of antennomeres III to XI about 1.0 : 1.5 : 1.3 : 1.3 : 1.3 : 1.2 : 0.9 : 0.9 : 1.1; ratio of length to width of antennomeres III to XI about 2.7 : 4.1 : 3.4 : 3.0 : 3.0 : 2.5 : 2.0 : 2.0 : 2.7 (Fig. 42). Penis (Fig. 45) relatively wider, 4.0 times longer than wide; subapex asymmetric, with a prominent notch at apical 1/7 of left margin and at apical 1/20 of right margin, apex pointed, moderately curved near apex and base from lateral view (Fig. 46); opening asymmetric, slender and close to right margin at apical 1/7, then abruptly widened, basal margin indistinct; endophallic sclerites composed of three visible sclerite, stick-like sclerite longest, about 0.7 times as length of penis; a small, triangular sclerite located near apex of stick-like sclerite; a wide, flattened sclerite located from base to apical 1/3 of stick-like sclerite, basal margin oblique and irregular.

Female. Length 5.5–6.3 mm. Similar to male (Figs. 26–27); antenna black but first three antennomeres paled, antenna a little shorter and narrower, ratio of length of antennomeres III to XI about 1.0 : 1.4 : 1.1 : 1.1 : 1.1 : 0.9 : 0.9 : 0.8 : 1.0; ratio of length to width of antennomeres III to XI about 3.0 : 4.0 : 3.0 : 3.0 : 3.0 : 3.0 : 3.0 : 2.6 : 3.0 (Fig. 43); some with filiform antenna, ratio of length of antennomeres III to XI



Figs. 42–49. *Apophylia velai*. 42. Antenna, male; 43. Antenna, female; 44. Antenna, female, variation; 45a. Penis, dorsal view; b: apex of penis, dorsal view, 'kaoi' type; 46a. Penis, lateral view; b: apex of penis, lateral view, 'kaoi' type; 47. Sternite VIII; 48. Gonocoxae; 49. Spermatheca.

about 1.0 : 1.3 : 1.1 : 1.1 : 1.0 : 1.0 : 0.9 : 0.8 : 1.1; ratio of length to width of antennomeres III to XI about 4.1 : 5.3 : 4.6 : 4.5 : 4.5 : 4.5 : 4.5 : 4.2 : 4.7 (Fig. 44). Gonocoxae (Fig. 48) wide, apex of each gonocoxa with seven to ten setae, base extremely slender. Sternite VIII (Fig. 47) well sclerotized, with dense short setae at sides, denser along apical margin, spiculum extremely long. Spermathecal receptaculum (Fig. 49) strongly swollen; pump short, moderately curved; spermathecal duct short, stout, shallowly projecting into receptaculum.

Host Plants. Boraginaceae: *Ehretia longiflora* Champ. ex Benth.; *E. dicksonii* Hance; *E. acuminate* R. Brown.; *E. resinosa* Hance.

Notes. The shape of the aedeagus apex is variable. The specimens with the short, sharp apex were described as *A. velai*, while specimens with longer, flattened apex were described as *A. kaoi* (compare Bezděk 2003a and Bezděk et Lee 2009). Because of the similarity in shapes of the opening and endophallic sclerites, we have concluded that *A. velai* and *A. kaoi* belong to the same species. Thus, *A. kaoi* is proposed to be a new synonym of *A. velai*.

Distribution. Taiwan. Specimens are common and widespread, making it the most common species in Taiwan. Most populations inhabit low elevation habitats (0–1,500 m).

Key to *Apophylia* species in Taiwan

1. Head black but mouthparts yellow; pronotum yellow with three black spots or dark brown with yellow margins ······················ 2
- Head and pronotum completely black ······· 3
2. Pronotum dark brown with yellow anterior and posterior margins; labrum blackish brown; male metasternum modified, bearing large symmetrical protuberance ··· *A. beeneni*
- Pronotum yellow with three black spots (median and two lateral); labrum yellow as same color as other parts of mouth; male metasternum not modified ·········*A. asahinai*
3. Legs black but tibiae paler ······*A. miyamotoi*
- Legs yellow but apices of tibiae darker ····· ···*A. velai*

CONCLUSIONS

Most of *Apophylia* species in Taiwan are widespread and common in lowland habitats (Figs. 16, 18–19). They are associated with certain species of Boraginaceae, including *Ehretia longiflora* (Figs. 50–51), *E. acuminate* (Fig. 52), and *E. dicksonii* (Fig. 53). The exception is *A. beeneni*, found only in south Taiwan (Fig. 17), possibly because of its association with tropical host plants, including *Carmona retusa* (Fig. 54), *E. resinosa* (Figs. 55–56), and *Trichodesma calycosum* (Fig. 57). Obviously *Apophylia* species in Taiwan are sympatric since they share the same hosts and distributions. Even *A. beeneni* shares the same host, *E. resinosa* with *A. asahinai*, they tend to "look different" from each other. *A. beeneni* have yellow mouthparts, pronotum, and legs, characters shared with *A. asahinai*. But Taiwanese populations of *A. beeneni* have darker pronota that are different from the yellow pronota of *A. asahinai*. The absence of apparently identical allopatric species suggests that sibling species are not present in Taiwanese *Apophylia*. A possible model of sibling species in chrysomelids in Taiwan occurs in the genus *Agetocera*. Sibling species of the *A. taiwana* species group may result from allopatric speciation (Lee *et al*. 2010). To confirm the occurrence of sibling species of chrysomelids in Taiwan researchers should work on their taxonomic problems based on sufficient material and fully explore their biology.

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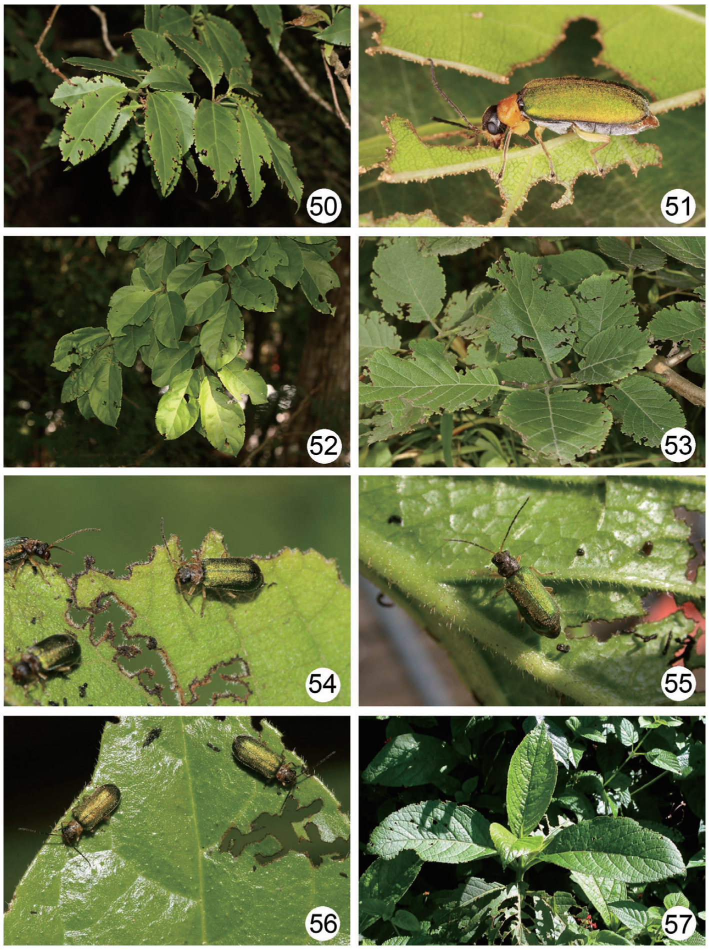

Figs. 50–57. Field observations. 50. Leaves of *Ehretia longiflora* with feeding marks; 51. One adult of *Apophylia asahinai* feeding on leaves of *E. longiflora*; 52. Leaves of *E. acuminata* with feeding damage; 53. Leaves of *E. dicksonii* with feeding damage; 54. Adults of *A. beeneni* feeding on leaves of *Carmona retusa*; 55. One adult of *A. beeneni* feeding on leaves of *E. resinosa*; 56. Adults of *A. beeneni* feeding on leaves of *E. resinosa*; 57. Leaves of *Trichodesma calycosum* with feeding marks.

Lee, Wei-Ting Liu, Mei-Hua Tsou, and Su-Fang Yu. We specially thank Hsueh Lee, Hsing-Tzung Cheng, Mei-Hua Tsou, Ren-Jye Chen, and Jung-Chang Chen for taking photographs in the field or on specimens. We thank Chris Carlton for reading the draft and editing for English style.

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台灣產翠螢金花蟲屬的分類回顧 (鞘翅目：金花蟲科：螢金花蟲亞科)

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摘要

李奇峰、J. Bezděk。2014。台灣產翠螢金花蟲屬的分類回顧 (鞘翅目：金花蟲科：螢金花蟲亞科)。台灣農業研究 63(1):1–16。

本文針對台灣產翠螢金花蟲屬 *Apophylia* 的種類做分類回顧，四個種類被視為有效種：斑胸翠螢金花蟲 *Apophylia asahinai* Chûjô, 1962、黃緣翠螢金花蟲 *Apophylia beeneni* Bezděk, 2003、黑翠螢金花蟲 *Apophylia miyamotoi* Kimoto, 1969 及黃腳翠螢金花蟲 *Apophylia velai* Bezděk, 2003；此外，兩個新的同物異名被提出：*Apophylia taiwanica* Bezděk, 2003 為 *A. asahinai* Chûjô, 1962 的新同物異名，*Apophylia kaoi* Bezděk and Lee, 2009 為 *A. velai* Bezděk, 2003 的新同物異名。不同性別的診斷特徵以線圖描繪；在台灣，金花蟲同胞種 (sibling species) 的發生是否可能發生的議題也在此討論。

關鍵詞：金花蟲、分類學、內囊骨片。

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Effects of Roasting *Camellia tenuifolia* Seeds with/without Shells on the Quality of Seed Oil

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Abstract

Hsieh, C. M., J. C. Yang, D. S. Chen, Y. C. Chuang, E. I. C. Wang, and Y. L. Lee. 2014. Effects of Roasting *Camellia tenuifolia* Seeds with/without Shells on the Quality of Seed Oil. J. Taiwan Agric. Res. 63(1):17–29.

Camellia tenuifolia is an indigenous camellia oil tree species native to Taiwan. Its fruit is smaller in size than the big-fruit species *C. oleifera*. With a lower annual oil yield and healthful ingredients to human body, the *C. tenuifolia* seeds oil has been considered a valuable oil to Taiwanese folklore. Generally the seeds of camellia species have a hard shell, while the shell of *C. oleifera* seeds is easy to make crack because of the bigger gaps between shell and seed kernel. Their seeds are also more uniform in size and the shells are easier to be removed. When processing for oil, *C. oleifera* seeds are usually shelled before pressing. On the other hand, seeds of *C. tenuifolia* have a variety of seed sizes and tough shell, with smaller gaps between shell and seed kernel. Thus, its seeds are more difficult to remove shell and hence, frequently *C. tenuifolia* seeds are directly pressed for oil without shelling. In this study, seeds of *C. tenuifolia* with or without shell were treated under different roasting conditions, from 110 to 130℃ for 5 to 10 min, and then were pressed for seed oil. Physico-chemical characteristics of the seed oils, including oil yield and stability index, acid value, peroxide value, smoke point, phenol content and reducing power, were analyzed. Results indicated that shelled seeds produced 13% more oil than that with shell on. All tested oils had acid value less than 1.0, peroxide value less than 10.0, and smoke point greater than 200℃. Results suggest that with or without the shell, the pressed oils all reached the food standard of general pressed oils. Regardless of with or without the shell, along with the increasing intensity of roasting, the phenol content and reducing power also increased. At suitable roasting treatment conditions, the oil quality will be better and oil be more stable during storage.

Key words: *Camellia tenuifolia* seed oil, Shell, Roasting, Oil quality, Oil oxidative stability.

INTRODUCTION

Consumption of oleic acid has been proven to reduce the risks of cardiovascular diseases (Kris-Etherton 1999; Sales-Campos *et al*. 2013). Tea oil camellia seed oil (also known as camellia oil) has high content (up to or even > 80%) of oleic acid (Zhong *et al*. 2007) and thus is also called “the oriental olive oil”. In Chinese families, camellia oil is a culinary oil with a history over two thousand years. In sixteen century Shizhen Li (1518–1593 AD) touted the oil’s functions and wrote in his re-

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nowned ancient book “Compendium of Materia Medica”. It has deeply influenced in the Chinese culture since then, and many therapeutic remedies involve the camellia oil.

Modern scientific research has also proved the oil’s functions, including the reduction of oxidation, inflammation, hyperlipidemia and the occurrence of neoplasm, the protection of heart and liver, and the improvement in immune system (Li *et al*. 2011). Moreover, camellia oil is frequently incorporated in varied folk medicinal prescriptions. In response to the functions of camellia oil carried down from ancestors, some researchers have focused on its ingredients to identify or explain these functional mechanisms. They found tea polyphenols and tea saponins are unique to camellia oil (Li *et al*. 2011). Additionally, two lignans (one is sesamin) found in the *Camellia oleifera* oil were identified to possess good anti-oxidation activities (Lee & Yen 2006). These studies are mere beginnings. Many remediation formulae have been validated through food incorporated with camellia oil to provide said functions and health benefits. Thus, this is still a domain urgently awaits further investigation. These functions include mitigation of gastroesophageal reflux, stomach ulcer, asthma, blood sugar, cough, skin health, anemia, constipation, blood circulation, and tonic for postnatal delivery.

There are many varieties of camellia oil trees in mainland China, and most of them belong to species *C. oleifera*, which bear bigger fruits compared to an indigenous species *C. tenuifolia* of Taiwan, mainly distributed in broadleaf forests of the north, with a comparatively lower annual yield. The oil value from *C. tenuifolia* is sold at a substantially higher price than those from *C. oleifera*. One reason is the low yield of seeds from *C. tenuifolia* and the other is its higher bioactivity being claimed. For maintaining the claimed functions, pressed oil without refinement is the main products on Taiwan’s market. In Taiwan, most camellia oil trees are cultivated in organic management with no pesticides and chemical fertilizers, only few cases using a small amount of natural fertilizers, in order to meet the regulation of organic farming and to obtain high quality oil products.

The commonly seen camellia oils in Taiwan marketplace are pressed from *C. oleifera* seeds. Fruit of the species has a diameter of ca. 3–5 cm, holding 2 to 8 seeds inside, and the seeds are 1–1.5 cm in diameter. The indigenous *C. tenuifolia* has smaller fruit sizes of ca. 1–3 cm in diameter, with thinner pericarp, and each fruit holds 1 to 3 seeds. The diameter of the seeds is ca. 0.5–2 cm. The seeds of oil camellia have a hard outer shell, which accounts for ca. 20% of dry seed weight. After oil camellia fruit are collected and dried (either by sun or under shade), seeds separate from the fruit shell; when the moisture content reduced down to about 5%, the seed kernels will separate from the seed pericarp. For *C. oleifera*, the interstices among kernel and shell are about 1–3 mm; whereas, those for *C. tenuiflora* are 0.5–2 mm with a tougher shell texture. In Taiwan, the commonly deployed shelling devices for oil seed camellia contain two rollers with adjustable gaps. By adjusting the gap distance to slightly smaller than the seed sizes and the rollers are activated after the seeds are poured in, the rolling action causes the shell to crack and separate from the kernel. Due to the more uniform seed size and larger gap between kernel and the shell, seeds of *C. oleifera* can be cracked easier and achieved 80% shelling rates after 2 passes in the usual shelling operations by commercial operators. However, seeds of *C. tenuifolia* often vary in sizes, having tight gap between kernel and the shell. Therefore, it will cause damages to the surface of larger kernels or even crack them due to the smaller roller gaps. In contrast, a larger roller gaps would shell the smaller seeds ineffectively. As a result, producers of *C. tenuifolia* oil in Taiwan may either remove the seed shells before processing or retain them when pressing for oil.

In this study, seeds of *C. tenuifolia* have been sorted according to sizes and proceeded

to shell to ensure be 100% shelled by inspection. Two streams of seeds with or without shell were roasted under 110 to 130℃ for 5 to 15 min. The treated seeds were cold-pressed to produce oil, and the quality and characteristics of the collected samples were then analyzed and compared.

MATERIALS AND METHODS

Camellia seeds and oil pressing process

The seeds of *C. tenuifolia* were harvested from trees growing in northern Taiwan, dried at room temperature in a shade, and then removed capsule's pericarps. A coffee bean roaster (ET-2, Xiong-Bang Ltd., Taoyuan, Taiwan) was used to roast the kernels at temperatures of 110, 120 and 130℃ for 5, 10 or 15 min as in our previous study (Hsieh *et al.* 2013). The roasted kernels were practiced as a general manufacturing process commonly used in Taiwan. The yield was calculated by the weights of kernels with cake cloth subtracting the weights of oil cakes (with the cloth) after pressing and divided by the kernels' weight (%).

Acid value, peroxide value, and smoke point

Acid value (AV) was determined as that reported in the previous study (Hsieh *et al.* 2013) by an auto-titrator 785 DMP Trino (Metrohm, Switzerland) following the instructions of the instrument. The oil peroxide value (POV) was determined according to the AOCS Official Method 965.33, with an oil weight 2.50 g (a half of the standard method) as previously described (Hsieh *et al.* 2013). The oils were preserved at 4℃ for the analysis of AV and POV. In order to simulate a household oil storage condition, the oil bottles were opened and closed occasionally during the storage period. Smoke point was monitored by using 2–5 mL of oil on a hotplate (IKA C-MAG HS7 IKAMAG®, Staufen, Germany) when smoke rose from the oil surface during continuing heating.

Oil stability index

Oil stability index (OSI) assay is a method of evaluating oil stability. It is the time (hour) of an oil sample that achieves a maximum change in conductivity caused by oxidation at 110 or 130℃ (Lampert 1999). The increasing conductivity is resulted from the production of volatile organic compounds, such as ketones and aldehydes derived from oxidized fatty acids. The analytical method followed the method of the previous study (Hsieh *et al.* 2013). A Rancimat apparatus (873 Biodiesel Rancimat, Metrohm AG, Switzerland) was used: the OSI of each oil sample (3.00 g) was monitored at temperatures of 110, 120 or 130℃, under continuous aeration at 10 L h^{-1} air flow.

Total phenol content

The method of Singleton & Rossi (1965) was modified for the oil's total phenol analysis (Hsieh *et al.* 2013). Gallic acid (GA) (Sigma Co., USA) was used as a standard, dissolving in distilled water at concentrations of 0, 0.1, 0.2, 0.3, 0.4, and 0.5 mg mL^{-1}.

Reducing power

The analytical method developed by Oyaizu (1986) and modified by Hsieh *et al.* (2013) was used to analyze the pressed oil samples. Standard trolox prepared in methanol (0.08, 0.2, 0.4, 0.6, and 0.8 mM) was used to build a standard curve for quantification.

RESULTS

Production of cold pressed oils

Production of Camellia oil from roasting shelled and shell-on *C. tenuifolia* seeds at 110 to 130℃ for 5 to 15 min was listed in Table 1. The production of oil for kernels without the shell was 30.5 g ± 1.5 g oil per 100 g, which was about twice the production of shell-on seeds (14.0 g ± 2.1 g oil per 100 g). Because shell weights were about 20% of seeds, after deducting the weights of the shells, the net pro-

duction of shell-on seeds increased to 17.6 g ± 2.6 g oil per 100 g (deduced by calculation, shown in the parentheses in Table 1). Apparently, oil production of the shell-on seeds was about one-half of that of kernels without the shells. Comparing the effects of different roasting conditions on oil production, the production tended to slightly decrease with increasing roasting intensities [The black bars show the results for shell-on seeds; white bars for shelled seeds; and gray bars represent for the deduced quantity (Fig. 1)]. When comparing seeds of the most intensive roasting treatment (at 130℃ for 15 min) with the non-treated seeds, the shell-on seeds showed a difference in oil production by 7.8% based on the net kernel weights. For the shelled seeds, the production difference was 3.7%. Again, it indicated that there was a two-fold difference in whether shells remained or shelled.

Acid value of oils

Acid value (AV) is the amount of free fatty acid per 1 g of oil that can be neutralized by KOH (in mg). The higher the values, the greater the degree of triacylglycerols become hydrolyzed. Thus, the acid value represents an inverse indication of the oil quality. AV-1 represents the acid values of the freshly-pressed oils and AV-2 represents the acid values of oils stored at 4℃ for 1.5 year (Fig. 2). The AV-1 of shell-on roasted treatments had acid values

Table 1. Comparison of oil production and quality of *Camellia tenuifolia* seeds pressed with and without shells.

AVG ± SD[z]	Shell	No Shell
Production	14.00 ± 2.10 (17.60 ± 2.60)[y]	30.50 ± 1.50
AV-1	0.81 ± 0.12	0.64 ± 0.11
POV-1	4.99 ± 2.49	3.34 ± 1.36
POV-2	5.73 ± 3.01	3.22 ± 1.13
SP	216.8 ± 7.40	211.40 ± 5.40

[z] Average ± standard deviation. Data calculated from all oil samples, including non-roasted and roasted. Units: Production, g oil per 100 g kernels; AV-1, acid value, mg KOH g^{-1} oil; POV, peroxide value, meq peroxide kg^{-1} oil; -1 and -2 representing a two-month-gap determinations between them stored at 4℃ ; and SP, smoke point, ℃ .

[y] Data in the parentheses is the net production of shell-on seeds, deducting 20% shell weights from the raw material weights.

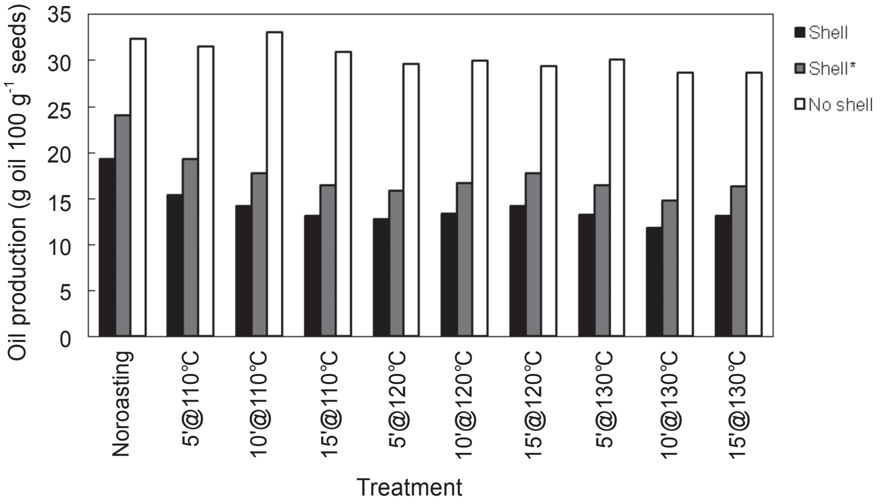

Fig. 1. Oil production of *Camellia tenuifolia* seeds pressed with and without shells treated by different roasting conditions. Shell*, values are deduced from the sample's weight after deducting 20% shell weights.

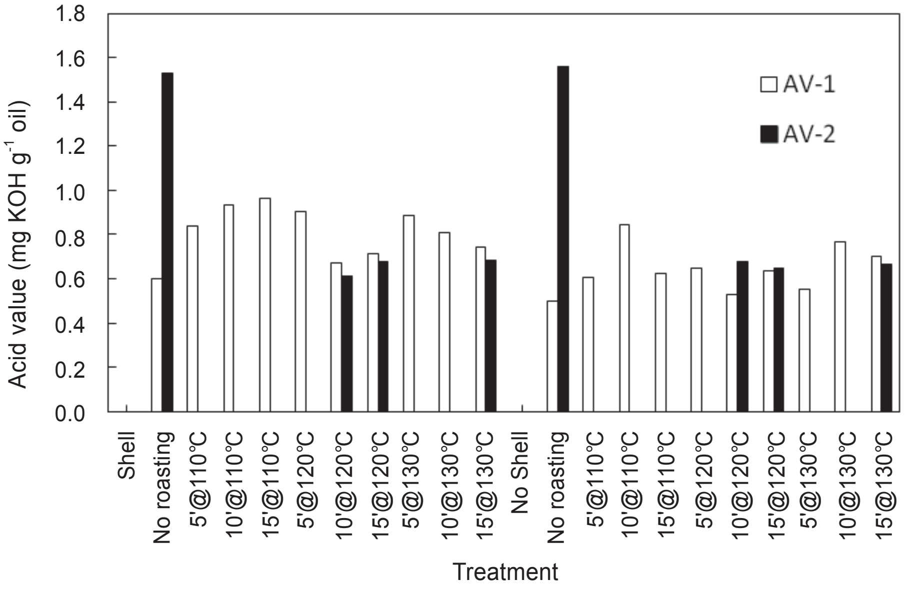

Fig. 2. Acid values (AVs) of pressed camellia oils with and without shells treated by different roasting conditions. AV-2 data were analyzed after 1.5 year cold storage at 4℃; AV-1 data were determined at time of oil pressing.

between 0.60–0.96; those without shells had acid values between 0.50–0.85. The lowest acid value was found in the oil from unroasted seeds with respective acid values of 0.50 and 0.60 for shelled and shell-on seeds. The average acid values of these 2 groups were 0.64 ± 0.11 and 0.81 ± 0.12, respectively (Table 1). Thus, the results indicated that shelled seeds produced oils of better quality than those pressed with shell-on.

Comparing the different roasting conditions, all oils had acid values < 1.0, indicating good quality; with increasing intensity of roasting, values of AV changed in an M-shaped curve. For both with- and without-shell seeds, the optimal roasting condition was at 120℃ for 10 min, where the respective AV values were 0.67 and 0.53. The oils of better AV-1 seeds including those roasted at 120℃ for 10 and 15 min and those roasted at 130℃ for 15 min were stored at 4℃ for 1.5 year and their AV values were also determined (AV-2, Fig. 2). Results indicated that oil AV values were increased greatly in the unroasted seeds (> 2 times the fresh oils), while values for the with- and without-shell oils were similar as the fresh oils.

Analysis of peroxide value of oils

The peroxide value (POV) of oil is the amount of peroxide substances expressed as milli-equivalent (meq peroxide) in 1 kg of oil. The higher the oil POVs, the greater the degrees of oxidation and the oil quality get worse. In this study, the average POV-1 values for seed oils of *C. tenuifolia* from with- and without-shell seeds were 4.99 ± 2.49 and 3.34 ± 1.36, respectively. After storing at 4℃ for 2 mo., the POV-2 values became 5.73 ± 3.01 and 3.22 ± 1.13, respectively (Table 1). Results indicated that seeds without the shell produced oils of better quality than that of shell-on oils. After 2 mo. of cold storage, the POV values of the shelled did not change, whereas the shell-on pressed oils had an average increase of 0.74. The effects of roasting conditions on the oil POVs were graphed in Fig. 3. Oils from seeds without the shell generally had POVs decreased with increasing intensity of roasting. The value of POV-1 decreased from 5.6 to 2.1 and the value of POV-2 maintained similar extent after 2 mo. of storage. The oils from

shell-on seeds with lower roasting intensity, however, tended to have higher POVs than the unroasted seeds (4.0). For those roasted at the conditions between 110℃ (5–15 min) and 120℃ for 5 min, the POVs reached 7.0–8.0, while those shell-on seeds treated with higher roasting intensity (120℃ for 15 min and treatments at 130℃) produced oils of POVs < 3.0, less than the unroasted shell-on samples. The highest roasting intensity of 130℃ for 15 min produced oil with POV for only 1.9. It is worth noting that seeds roasted at 120℃ for 10 min up to 130℃ for 15 min showed no apparent changes in POVs during 2 mo. of cold storage. For all oil samples cold-stored for 1 year, their POV-3 values increased to tow-fold of the original ones (Fig. 3), indicating that peroxide gradually accumulates in all samples. The oils from more-intense roasting treatments appeared to accrue peroxide species at slower paces than those unroasted or low-intensity roasting and thus had lower overall POVs. After 1 year of cold storage, the seeds treated at 130℃ for 15 min had POVs of 4.11 and 4.96 for seeds with and without the shell, respectively.

Smoke point of oils

At high temperatures, oil or fat will produce bluish hazy smoke because breakups of triglycerides. The specific temperature at which smokes first appear is called smoke point. Generally, the more stable the oil, the higher the smoke point. For unroasted seeds both with- or without-shell, the smoke point was identical, at 207℃ . After roasting at different conditions, the with- and without-shell oils had average smoke points of 216.8℃ ± 7.4℃ and 211.4℃ ± 5.4℃ , respectively (Table 1); all smoke points were greater than 200℃ (Fig. 4). The with-shell seeds along with increasing intensity of roasting would produce oils with increased smoke points up to 228.0℃ (at roasting condition of 130℃ for 10 min). However, at the treatment of 130℃ for 15 min, smoke point decreased to 206.1℃ . For the without-shell seeds along with the increasing roasting intensity, the smoke points of oils first increased and then decreased. The highest smoke point of 219.3℃ was observed for seeds roasted at 120℃ for 5 min.

Indices of oxidative stability of oils

Analysis of oil oxidative stability provides important reference to keeping or storing

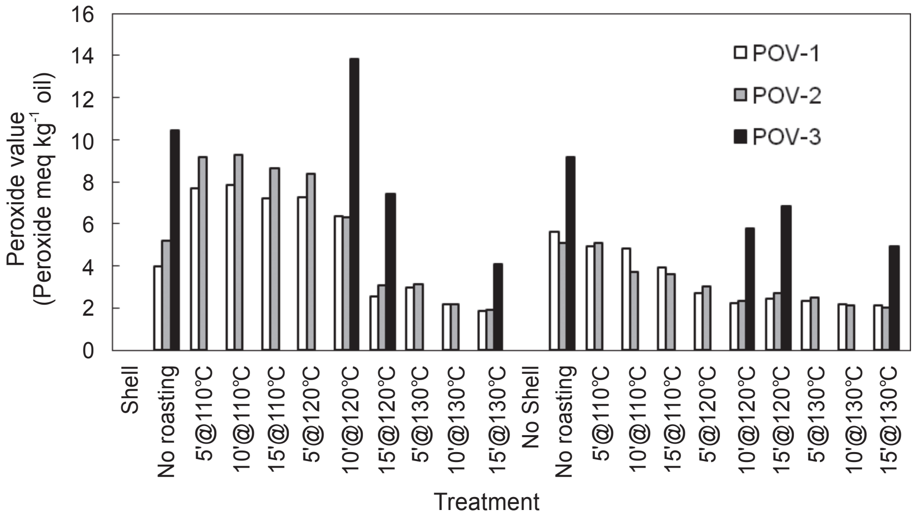

Fig. 3. Peroxide values (POVs) of pressed camellia oils with and without shells treated by different roasting conditions. POV-2 and POV-3 were determined with the oil samples stored at 4℃ for 2 mo. and 1 year, respectively, after the analysis of POV-1.

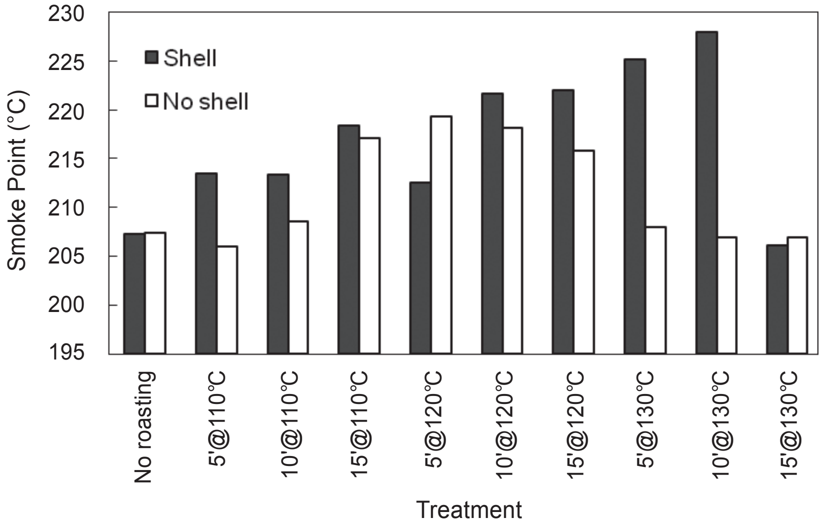

Fig. 4. Smoke points (SPs) of pressed camellia oils with and without shells treated by different roasting conditions, at 110, 120 or 130℃ for different times.

quality oil. By the Rancimat method for analysis, in which 10 L h^{-1} of air is fed to oil sample maintained at 110, 120, or 130℃ to facilitate oil oxidation, and the oil stability index (OSI) is then measured. The index points were determined at the time of rapid oxidative degradation of oils and hence, the oxidative stabilities of different samples were compared in parallel. As shown in Fig. 5, the values of OSI in seeds of *C. tenuifolia* with- or without-shell varied to the intensity of roasting. The OSI of the pressed oils indicated that for each 10℃ temperature increment, values of OSI changed about halved. The OSI of oils from with-shell seeds had lower values than those from without-shell seeds. The OSI of the unroasted and those roasted at 130℃ appeared

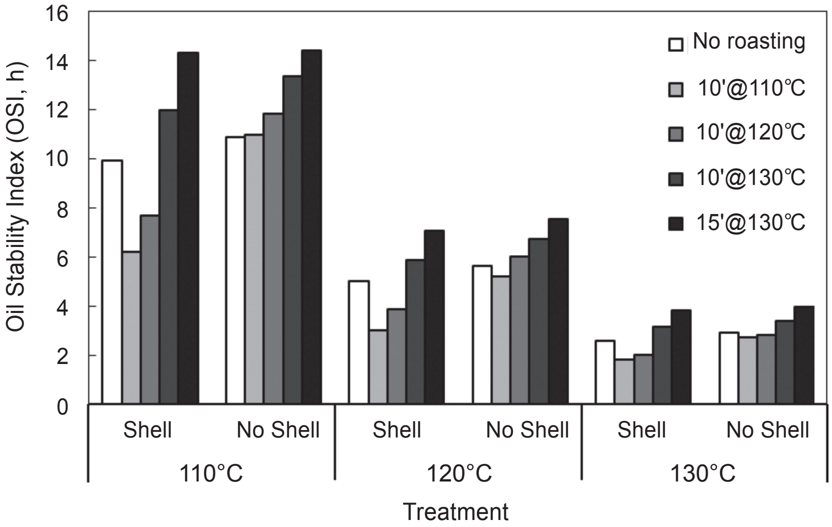

Fig. 5. Oil stability indices were determined with the pressed camellia oils, with and without the shell, treated by different roasting conditions, at 110, 120 or 130℃ for different times.

to be similar. The OSI values of the unroasted seeds at 110, 120, and 130℃ for the without-shell seed oils were higher than those of the with-shell seed oils with the differences of 0.96, 0.60 and 0.33 h, respectively. Comparisons of the results from different roasting conditions suggest that a positive correlation of OSI value exists in the without-shell oils with the roasting intensity, i.e., the higher the roasting temperature and longer the time and the higher the OSI value. Conversely, for the with-shell seeds roasted at lower intensities (110 or 120℃ for less than 10 min), the OSI values were significantly lower than the unroasted ones; whereas, when roasted at 130℃ for 10 or 15 min, the OSI values of the oils were higher than the unroasted ones. Regardless of with- or without-shell, the oils with the highest OSI values were roasted at the highest intensity (130℃ for 15 min). For the with-shell seed oils, OSI values were at 14.28, 7.04, and 3.80 h when tested respectively at 110, 120, and 130℃. To the without-shell seed oils, OSI values were at 14.41, 7.55, and 3.94 h for the same temperature series. The differences in OSI between the with- and without-shell seeds were 0.13, 0.51 and 0.14 h at 110, 120, and 130℃, respectively.

Phenol content and reducing power of oils

The phenol content of seed oils were shown in Fig. 6A. The content tended to increase with increasing roasting intensity, and there appeared to be no distinctive trend in difference of phenol content between the with- and without-shell seed oils. The highest phenol content was found in the most intense roasting conditions (130℃ for 15 min); the with- and without-shell seeds produced oils with 0.089 eq ± 0.004 eq and 0.078 eq ± 0.003 eq GA mg mL^{-1} oil, respectively. The oil reducing power analysis results are shown in Fig. 6B. Both the with- and without-shell seeds had reducing power increased with increasing roasting temperature. As shown, in addition to the similar results as unroasted treatments, the without-shell seeds had higher reducing power than the with-shell seeds. The highest values of oil reducing power were found from the highest roasting intensity treatments (130℃ for 15 min). The respective values for the with- and without-shell oils were 0.318 mM ± 0.010 mM and 0.353 mM ± 0.004 mM Trolox, respectively. Comparing the results shown in Fig. 6A and Fig. 6B, it is apparent that there was a positive correlation between oil phenol content and its reducing power.

DISCUSSION

This study mainly investigated the effects of roasting *C. tenuifolia* seeds with- or without-shell at different conditions on the resulting oil quality and properties. The primary components of the pericarp shell are lignin, pentosans, saponin and tannin, largely hydrophilic substances. It contains practically no oil (Yang 2009; Guo *et al*. 2010) and is of high water solubility. The fragments of shells would absorb oil resulting in a lower oil yield of shell-on seeds than that of shelled seeds. The main purpose of roasting treatment is to reduce moisture content in the kernels as well as to coalesce oil droplets at elevated temperature so that oil production improved. However, the procedure adopted in this study employs the roasting and then cooling down to room temperature before pressing step. Instead of increasing oil production, seed oil was slightly decreased by the process, the results similar to our earlier report (Hsieh *et al*. 2013). The plausible reason is that at room temperature, small quantities of more saturated fatty acids might coalesce with the substrate tissue or residues to decrease oil production. On the other hand, it is significant that the without-shell seeds produce 13–15% more oil, than those with-shell ones. In a report by Yang (2009), shelling treatment resulted in a gain of 30% oil than the shell-on seeds when solvent extraction was the method of oil production. Thus, seeds with- or without-shells will significantly affect oil production. Though pressing the shell-on seeds reduces the costs of labor and machinery, in

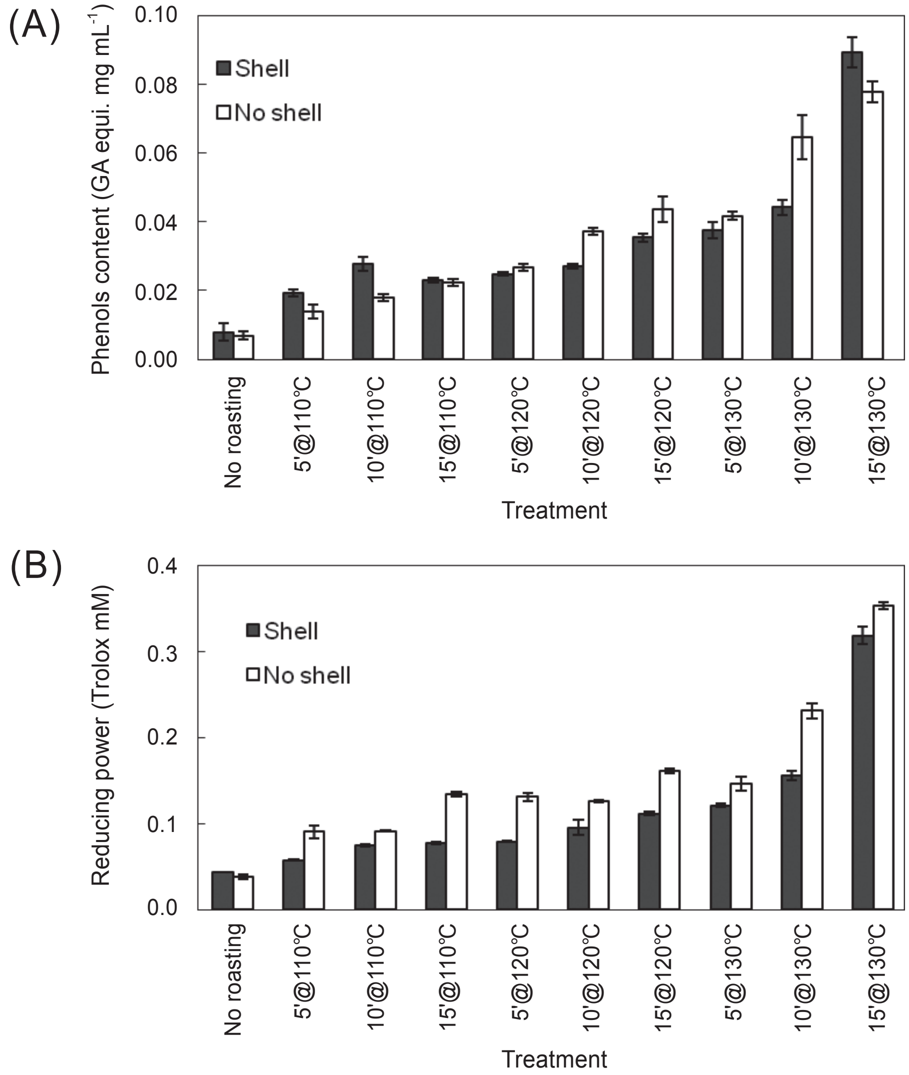

Fig. 6. Phenol content (A) and reducing powers (B) of pressed camellia oils with and without shells, respectively, treated by different roasting conditions, at 110,120 or 130℃ for different times.

any case, the principal consideration in using shell-on or shelled seed is oil quality, which is also the main purpose of this study. We investigated the effect of with- or without-shell on the characteristics of AV, POV, SP, and OSI of the resulting oils. In addition, the pressed seed oil from *C. tenuifolia* oil is well-known for its healthy nutrition facts and therapeutic effects (as some claim). Scientists are eager to analyze its active ingredients and quick functionalities. Shen *et al*. (2012) found that camellia oil contained certain lipophilic phenolic compounds which had antioxidant activities that might be related to the desired functionalities. Therefore, detecting phenol content in the oil becomes imperative, particularly by using Folin-Ciocalteu's reagent to analyze total phenols (Singleton *et al*. 1999). As a consequence, the reducing power with antioxidant capacity of seed oil was also analyzed using the reductive capability of ferricyanide ions to ferrocyanide ions (Oyaizu 1986). The results could serve as

a complement to the understanding of the antioxidative activity of camellia oil.

The AV and POV values of oils are the most important quality criteria of food oils. The AVs of all oil samples (freshly pressed) were less than 1.0. As the national standard for pressed camellia seed oils is wanting, and at present, the pressed peanut oils should have AV less than 2.0 and pressed sesame oils should be lower than 4.0. Comparatively, the quality of camellia seed oils obtained in this study was superior. Regardless of with- or without-shell seeds, the lowest AV value from freshly pressed oils (AV-1, Fig. 2) was from unroasted seeds (0.50–0.60); and for the roasted seeds, those treated at 120℃ for 10 to 15 min had better AVs (0.53–0.71). After cold storage at 4℃ for 1.5 year, AV values of the roasted oils did not increase; whereas, AVs of the unroasted oils increased significantly. The possible reasons will be discussed later in the text. As for POVs of the oils (Fig. 3), all samples had values less than 10. Again, there was no national standard for pressed camellia oils. In general, POV of pressed oils must be lower than 20. Therefore, the experimentally produced camellia oils were all had a good quality. Regardless whether the seeds were pressed with- or without-shell, all oil samples still maintained in a POV value less than 20 after 1 year of cold-storage at 4℃ . Moreover, the oils from highest-intensity roasted seeds had the lowest POV values. From the results of AV and POV measurements, suitable roasting treatment for both with- and without-shell camellia seeds tended to decrease the oil POV values and inhibit the increase of AV value during storage. Consequently, roasting treatment is beneficial to the shelf life of camellia oil keeping food safe for ingestion by consumers.

From the oil stability index (OSI, Fig. 5), it is expected that roasting treatment would obtain a similar effect as that of POV. Generally, roasting treatment reduces POV and increases OSI, implying that camellia seeds so treated contained more antioxidant substances. This is in turn proven by the oil phenol content (Fig. 6A) and reducing power (Fig. 6B). Particularly, for the shelled camellia seeds, the increasing roasting intensity caused POVs to decrease and OSI to increase; suggesting that seed kernels released more antioxidant substances because of the roasting. Conversely, the shell-on camellia seed oils at lower roasting intensities (110–120℃ for 10 min) produced both POV and OSI inferior to that of unroasted seed oils. Therefore, higher intensities (130℃ for 10 or 15 min) were required to allow the resulting oils having better oxidative stability than that of unroasted one, and reach similar POV and OSI values as those without-shell seed oils. Based on the results, we speculate that at lower roasting intensities, the with-shell camellia seeds would have oxidative substances eluded from the shells causing the POV and OSI values of the oils to be inferior to the unroasted one. When roasting temperature and duration were increased, the release of kernel antioxidant substances instead overcame the shell-derived oxidants leading to reduced POV and increased OSI values for the oils. Analysis of the phenol content in oils (Fig. 6A) indicated that presence or absence of shell did not affect the contents. The reducing power analysis (Fig. 6B), however, consistently indicated that roasting treatment rendered without-shell seed oils to have better reducing power than those with-shells. These results have proven that presence of shells tended to reduce the antioxidant capacity of the resulting oil. Regardless of the shell conditions, the most stable oils were from seeds roasted at the highest intensity of 130℃ and 15 min. Xu *et al*. (2007) also found that heat treatment increased phenol content in the orange peel extract and increased its antioxidant capacity. The results were in congruency with our earlier study results (Hsieh *et al*. 2013), indicating that suitable roasting treatment increased phenol content in the pressed oil and its anti-oxidative capacity. The increased phenol content and reducing power of the roasted seeds may be resulted from non-enzymatic browning reaction, such as Maillard

reaction, caramelization and chemical oxidation of phenols (Manzocco *et al*. 2000). As seen, color of oils pressed from roasted seeds gradually darkened following the roasting intensity.

The presence or absence of shells exerted significant effects on the SP of the oils (Fig. 4). The value of SP of the with-shell seed oils tended on average to be 5℃ , higher than those from without shell seeds (Table 1). The SP of the without-shell seed oils varied with the roasting intensity in an inverse V-shaped pattern, SP increase initially and then decrease, which tied in well with the changes in oil AV values. In roasting treatments, the AV changed with roasting intensity in an M-shaped pattern, indicating that the AVs of mid-intensities (for both with- and without-shell seeds) were less than those of low- and high-intensity roasting conditions. For which, the mid-intensity roasting led to lower free fatty acid contents in the oils. These results are in agreement with the SPs that higher values indicated less free fatty acid contents. Therefore, roasting camellia seeds at mid-intensity facilitates oil production with lower AVs. In the storage experiment, there were no significant AV changes for roasted seed oils stored at 4℃ for 1.5 year. Whereas, those from unroasted seeds showed significant AV increases after storing at the same conditions for 1.5 year. A most probable cause is the enzymatic activities persisting in the cold-pressed and cold-stored oils. Megahed (2011) found that by treating wheat at 70℃ for 30 min, lipase activity was inhibited and decreased AV of the subsequently produced oil. Therefore, high-temperature roasting treatment can effectively denature the lipase in the seeds which in turn inhibits hydrolysis reaction producing free fatty acids and causes AV to remain stable.

This study has proven that after suitable roasting, *C. tenuifolia* seeds could produce oils of enhanced quality, including better POVs, SPs, OSI, phenolic compounds, reducing powers, etc. In addition, roasting treatment significantly inhibited AV increase during storage. Overall, disregarding the slight decreases or changes of oil SP and AV, for *C. tenuifolia* seed oils, the best roasting conditions was the highest intensity at 130℃ for 15 min, in which the produced oils had the best oxidative and storage stability, the highest phenols and the strongest reducing power. Additionally shelling of seeds is advised that would increase oil production and provide the best oil quality.

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苦茶籽帶殼與否及炒培處理之榨出油品質比較

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摘要

謝靜敏、楊正釧、陳德旭、莊曜駿、王益真、李雅琳。2014。苦茶籽帶殼與否及炒培處理之榨出油品質比較。台灣農業研究 63(1):17–29。

台灣特有苦茶品種 *Camellia tenuifolia* 果實較一般大果品種 *C. oleifera* 小，並且產量少，其壓榨油具有特殊的人體保健功效，所以成為台灣民間珍貴的食用油。苦茶籽有一層硬質種仁殼，大果種因為殼質較脆，殼與仁之間的間隙大，並且種子大小相近，所以脫殼容易，一般加工製程會經過脫殼再榨油。然而小果種的茶籽殼質韌、殼與仁之間的間隙小，並且種子大小不一，所以脫殼相對不容易，故有一部分小果種苦茶籽沒有經過脫殼就直接榨油。本研究分析小果種苦茶籽帶殼或脫殼後，再處理不同的炒培條件 (介於110–130℃ , 5–15 min)，分析其產油率、油脂酸價、過氧化價、煙點、油脂安定指數、酚類化合物含量及還原力。結果顯示，無殼者產率高於帶殼者 13%。所有試驗的油脂酸價均 < 1.0，過氧化價 < 10.0，煙點 > 200℃，顯示均達一般壓榨油脂的食用標準。不論是否帶殼，隨著炒培條件的增強，酚類化合物含量及還原力隨之增加，並且在合宜的炒培處理條件下，油脂品質較好、儲藏安定性較佳。

關鍵詞：小果種苦茶籽油、種仁殼、炒培、油脂品質、油脂氧化安定性。

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水稻生育階段預測模式之建立與驗證

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摘要

林士閎、呂椿棠、卓緯玄、呂秀英。2014。水稻生育階段預測模式之建立與驗證。台灣農業研究 63(1):30–42。

本研究主要目的在建立國內現有 3 個重要中晚熟品種 (「台稉9 號」、「台農 71 號」及「台農秈 22 號」) 之三個重要生育時期 (50% 始藥期、幼穗分化期及 50% 抽穗期) 的水稻生育階段預測模式，作為推估水稻重要特定生育時期的依據，以有效執行田間栽培管理。利用參試品種在 2006–2010 年各兩期作不同插秧日期試驗，以各生育階段期間內每日的發育速率與有效積溫 (即生育度數，growing degree days; GDD) 建立線性回歸模式，並驗證模式之預測能力。首先將所有試驗資料以內部驗證方式進行建模與驗證，結果發現預測與實際發育速率間之差異的 95% 信賴區間皆包含 0，顯示預測誤差在可接受的 5% 顯著水準範圍內；再合併所有試驗資料建立各品種之 3 個生育階段的 GDD 預測模式，所得到截距與回歸係數之估值皆落在前述驗證程序所得模式之該兩個係數估值的 95% 信賴區間之內，顯示此等 GDD 模式是穩健的，由此可推知各品種達到各生育階段所需之 GDD。本研究亦發現不同品種在各生育階段的發育速率不盡相同，相較於「台稉 9 號」，「台農 71 號」稍早熟而「台農秈 22 號」稍晚熟，乃由於「台農 71 號」在 50% 始藥期至幼穗分化期間的發育速率較快，而「台農秈 22 號」在插秧至 50% 始藥期間雖發育速率較快但之後到 50% 抽穗期間發育速率變慢所致。因此為提升稻穀產量，不同品種應配合其關鍵生育階段施以適當的田間栽培管理。

關鍵詞：有效積溫、生育度數、生育速率、線性回歸模式、預測誤差。

前言

水稻為世界三大糧食作物之一，在水稻各生育階段當中，始藥期、幼穗分化期及抽穗期之發育情況都會影響水稻收穫產量 (Yoshida 1981; Bollich *et al*. 1999)。水稻穀粒產量受到每株穗數、每穗粒數等構成要素之影響，若在水稻重要特定生育階段時間點進行適當的田間栽培管理，例如水稻始藥期施用氮肥以提高有效分藥數可增加每欉穗數，於幼穗分化期施用氮肥促進幼穗分化可增加每穗粒數，在重要生育階段防治病蟲害等都能有利最終產量之提升 (Yoshida 1981; Slaton & Norman 1994)。水稻在這些重要生育階段的生長發育，皆受到氣象因子如氣溫、日長、日射量及降雨量等影響 (Yoshida 1981)。近年來由於全球氣候變遷，導致作物生長發育階段越來越難以掌握 (Hodges 1991)，因此，建立精確的水稻生育階段預測模式，做為推估水稻重要特定生育時期的依據，可有效執行田間栽培管理。

由於作物生長發育受基因型及環境的共同影響，建立作物生育階段預測模式可用來量化作物自發芽至營養生長、花芽分化、抽穗、開穎及成熟等生育階段與環境之間的關係 (Horie & Nagakawa 1990)。作物生育階段的時間能夠精準預測，對作物生長生理機制研究非常有幫助

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(Hodges 1991; Wang & Engel 1998)。為建立生育階段預測模式或作物物候模式 (crop phonological model)，研究者通常進行多次作物生長發育調查試驗，記錄該作物特定生育階段 (如營養生長期、生殖生長期及成熟期等) 之時間點及收集生長發育期間氣象資料，當試驗結束時，將這些特定生育階段的發育速率與相對應的氣象資料，利用線性或非線性關係的模式來配適，再以後續年度試驗資料來驗證所建模式的預測能力 (Whisler *et al*. 1986)。

作物受到氣溫影響的研究，始自於 Réaumur (1735) 所提出來的熱單位 (heat unit 或 thermal unit) 理論概念，認為作物的生長發育要達到一個階段，需要累積到一定的溫度。水稻的發育速率會隨著有效溫度 (effective temperature) 增加而上升，完成一個生育階段時期所需有效溫度為一個常數，稱為有效積溫 (effective accumulated temperature) 或稱生育度數 (growing degree days; GDD)；GDD 為每日平均氣溫減去特定溫度下限－基礎溫度 (base temperature) 所得剩下的溫度，若得到負值則設 GDD 為 0，也就是指作物生長發育停止 (Glimore & Rogers 1958)。Russelle *et al*. (1984) 指出氣溫對作物生長發育的解釋能力最高可達 95%，利用 GDD 做為溫度指標應用在作物發育速率上能有較合理解釋。

利用 GDD 建立水稻生育階段之預測模式，始於 1970 年代美國 Slaton 之 DD50 (degree days 50) 管理程式，DD50 的計算公式為每日最高溫 (94°F為上限) 加上每日最低溫 (70°F為下限) 之平均溫度減去基礎溫度 (50°F)，即為水稻每日生長所需的 GDD；該方法至今已累積 30 多年不同水稻品種之試驗資料，美國阿肯色州有近 60–70% 水稻農戶運用此程式預測水稻生育階段，其預測的誤差僅提早或延後 2 日 (Slaton & Norman 1994)。Norman *et al*. (2002) 在美國進行水稻多個播種日期的生長發育比較試驗，發現生育日數隨著插秧期越晚，生長發育到特定階段的時間就越短，且水稻生長發育到幼穗分化期、抽穗期及生理成熟期需要達到一定累積溫度。因此，即使在不同年度進行水稻生長發育比較試驗，發現相同品種在不同年度間的特定生長發育階段必需累積溫度大致上也差異不大 (Wilson *et al*. 2005; Frizzell *et al*. 2010)。

由於水稻生長發育也受到日長影響，Horie & Nakagawa (1990) 與 Chang *et al*. (2006) 均指出超過最適日長時間水稻會延遲抽穗開花。因此有些研究同時以 GDD 與日長作為自變數，建立光熱單位模式 (photothermal unit model; PTU 模式)，以預測水稻生長發育階段，但經評估只有幼穗分化期前的感光期生育階段才會受到日長影響 (Horie & Nakagawa 1990; Yin *et al*. 1997a, b)。Chiu (1993) 利用台灣 6 個水稻品種為材料 (「台中65號」、「台南5號」、「台農 67 號」、「台中 189 號」、「台中秈 10 號」及「台中秈 17 號」)，評估 GDD 模式、納入日溫與夜溫之修飾 GDD 模式以及加入日長的 PTU 模式對幼穗分化期之配適表現及預測能力，發現使用 GDD 模式配適良好，但使用同時包含 GDD 與日長的 PTU 模式之配適能力並沒有獲得改善且有更差的傾向，且插秧到幼穗分化期的發育速率對日長改變的反應只有一次效應，在剔除溫度效應後日長對發育速率的影響極微。其推測這是因為台灣地區一期作與二期作連續交替選拔的方式，在自然淘汰作用下，只有光週期鈍感的品系才會留存，建議仍以 GDD 預測模式來配適插秧至幼穗分化期的發育速率。

Chiu (1993) 僅針對水稻幼穗分化期建立 GDD 預測模式，且所分析的參試水稻品種在目前國內栽培面積已經很少甚至不再種植，因此本研究主要目的在建立國內現有 3 個重要中晚熟品種 (「台稉 9 號」、「台農 71 號」及「台農秈 22 號」) 之 3 個重要生育時期 (50% 始蘗期、幼穗分化期及 50% 抽穗期) 的 GDD 預測模式。利用 2006–2010 年 3 個品種於各生育階段內每日發育速率與其相對應之每日 GDD 建立線性回歸關係，探討 GDD 預測模式的配適性與預測能力，藉此推估各品種不同生育階段所需之 GDD，並比較各品種間在不同生育階段的發育速率變化差異，期能有利於田間栽培管理之參考。

材料與方法

試驗材料

本研究的 3 個參試品種為「台稉 9 號」(‘TK9’)、「台農 71 號」(‘TNG71’) 及「台農秈 22 號」(‘TNGS22’)，其中 ‘TNGS22’ 為秈稻 (indica rice)，其餘兩個品種均為稉稻 (japonica rice)。3 個品種皆為中晚熟品種，但 ‘TNG71’ 稍早熟而 ‘TNGS 22’ 稍晚熟。試驗於 2006–2010 年在行政院農委會農業試驗所試驗田進行，不同年度的參試品種不盡相同，2006–2008 及 2010 年皆有 3 個參試品種，而 2009 年僅有 ‘TNG71’及 ‘TNGS22’ 兩品種，且 2009 與 2010 年試驗兩期作皆有 3 至 4 個不同插秧期，因此 ‘TK9’ 共有 14 個年期試驗資料，而 ‘TNG71’及 ‘TNGS22’ 各有 21 個年期試驗資料。各年期的田間試驗皆採用隨機完全區集設計 (randomized complete block design; RCBD)，小區面積為 11.2 m (長) × 2.8 m (寬)，植栽密度為 0.28 m × 0.16 m，每品種各重複 3 次。

資料收集與整理

試驗期間調查 3 個品種於不同生育階段 (50% 始蘗期、幼穗分化期及 50% 抽穗期) 的生育日數。50% 始蘗期定義為每天調查小區內 50 欉水稻，直到水稻分蘗之欉數超過 50% 的日期；幼穗分化期之調查為每隔 1 日取 10 株水稻主稈鏡檢，直到幼穗長度達 2 mm 的植株超過 5 株以上的日期；95% 抽穗期為每天調查 50 欉的水稻生長發育，直到抽穗欉數達到 50% 的日期。

試驗期間並收集記錄每日氣溫資料，再計算 3 個參試品種於上述 3 個生育階段生育日數相對應的有效累積溫度 (即生育度數 GDD)，每日的 GDD 計算公式如式 [1]：

$$\sum\{ \frac{[T_{max} + T_{min}]}{2} - T_b\} \qquad [1]$$

其中 T_{max} 為每日最高溫，T_{min} 為每日最低溫，T_b 為生長發育基礎溫度，本研究假設水稻的生長發育基礎溫度為 10℃。

預測模式建立方法

本研究在假設水稻每日累積發育速率與相對應之每日 GDD 存在線性關係之基礎上，建立水稻 GDD 模式來預測其重要生育階段。因此，利用各品種試驗資料建立達到某生育階段前之期間內，每日累積發育速率與其相對應每日 GDD 間的簡單線性回歸關係如下：

$$Y = b_0 + b_1X \qquad [2]$$

式中 Y 為水稻達到某生育階段前之期間內每日累積發育速率，b_0 為截距 (intercept)，b_1 為回歸係數 (regression coefficient)，X 為該期間內每日 GDD。截距與回歸係數之估計，可透過最小平方法 (least square method) 求得。在作物生育期模式化過程中，某生育階段從開始到結束之期間內每日發育速率可設為達到該生育階段所需生育日數之倒數 (Horie & Nakagawa 1990; Shaykewich 1995; Wang & Engel 1998; Iannucci *et al*. 2008; Ceglar *et al*. 2011)；例如，‘TK9’ 之 2006 年一期作從插秧至 50% 始蘗期所需生育日數為 19 d，則該期間內每日發育速率設為 1/19 d^{-1}，因此期間內每日累積發育速率為 1/19、2/19、……及 19/19 d^{-1}。

考慮 3 個水稻品種同一期作在同一地區之相同氣候及栽培管理環境下各生育階段的發育速率可能不盡相同，因此分別建立 3 個生育階段 (插秧至 50% 始蘗期、50% 始蘗期至幼穗分化期、幼穗分化期至 50% 抽穗期) 之每日累積發育速率與每日 GDD 的線性回歸式，以探討各品種從插秧到 50% 始蘗期、再到幼穗分化期及最後達 50% 抽穗期之不同生育階段時所需的 GDD，並進行相同環境下品種間之相對發育速率差異比較。各生育階段的 GDD 預測模式除關係式顯著性測驗外，皆利用決定係數 (coefficient of determination; R^2) 判定配適能力，R^2 值在 0 與 1 之間，數值越大則代表模式解釋或配適能力越良好。GDD 預測模式之建立與驗證的各項計算，則利用 SAS 9.3 統計套裝軟體中的 PROC REG 進行分析。

預測模式驗證方法

為評估上述生育階段預測模式所得回歸係數的穩定度與預測能力，將各品種各生育階段的所有年期試驗資料劃分為訓練資料集 (training dataset) 與驗證資料集 (validation dataset)，以進行模式的內部驗證 (internal validation)。內部驗證使用留一法之交叉驗證 (leave-one-out cross validation) 進行，即在運算過程中每一次移除一筆資料藉以對建立的模式進行驗證工作，然後以剩下的資料建立模式，並重複進行 (Witten & Frank 2005)。因此，本研究在所有試驗資料中每次取出某年某期作某插秧日期的試驗資料作為驗證資料集，其餘資料則用來建立模式；例如 'TK9' 執行第 1 次的驗證資料集為 2006 年一期作資料，其餘 13 個年期試驗資料則作為建立 GDD 預測模式的建模資料集，因此共可執行 14 次，以此類推，'TNG71' 可執行共 21 次，'TNGS22' 也可執行共 21 次。每次執行程序中，先利用訓練資料集建立如式 [2] 的模式，再將驗證資料集達到某生育階段之實際有效積溫代入所建模式，以推估達到該生育階段的預測發育速率。由於達到該生育階段時的實際發育速率為 1，因此可藉由預測發育速率與實際發育速率之間的差異，來評估模式的預測能力，然後計算所有執行次數所得之發育速率誤差 95% 信賴區間 (confidence interval; CI)，倘 0 落在 95% CI 內，表示預測誤差在可接受範圍。除此，也計算所有執行次數所得回歸係數的 95% CI，以評估預測模式的穩定度。

最後各品種所有年期試驗資料再全部合併進行預測模式建立，除利用顯著性測驗與 R^2 評估模式配適性外，也檢視回歸式中的截距與回歸係數估值是否落在先前模式驗證程序中所得該兩個係數估值的 95% CI 內，倘未超過 95% CI 範圍外，表示預測模式的截距與回歸係數相當穩定，即可將該合併所有試驗資料所得回歸關係式作為預測模式，來預測不同水稻品種各生育階段所需 GDD，並比較各品種在不同生育階段的發育速率差異。

結果

各生育階段實際之生育日數與 GDD 資料整理

3 個參試品種 ('TK9'、'TNG71' 及 'TNGS22') 於三個生育階段 (插秧至 50% 始蘗期、50% 始蘗期至幼穗分化期、以及幼穗分化期至 50% 抽穗期) 經各年期試驗所調查的生育日數與 GDD 資料，分別整理如表 1 至 3，從變異係數 (CV 值) 可發現除 'TK9' 與 'TNG71' 之 50% 始蘗期至幼穗分化期外，所有品種於各生育階段調查之 GDD 在年期之間的變異，均甚小於生育日數之年期變異，尤其是 50% 始蘗期以 GDD 之年期變異遠低於生育日數之年期變異。比較 3 個生育階段之 GDD 與生育日數之年期變異，皆以 50% 始蘗期在不同年期的變異最大 (表1–3)。

各生育階段之 GDD 預測模式建立與驗證

從插秧至 50% 始蘗期、50% 始蘗期至幼穗分化期、以及幼穗分化期至 50% 抽穗期之不同生長期間內，'TK9'、'TNG71' 及 'TNGS22' 每日累積生育速率與每日 GDD 間回歸模式各經執行 14、21 及 21 次之驗證程序結果，每次所得 GDD 預測模式皆配適良好 (R^2 = 0.835−0.994，未列表)，計算所有執行次數所得模式之截距與回歸係數估值的 95% CI 如表 4 所示，各生育階段不同品種之間存有差異；將每次作為驗證資料集達到各生育階段期的實際 GDD (表 1–3) 帶入每次所得模式，估計出每次執行程序的預測發育速率，並計算所有執行次數建模所得預測發育速率的 95% CI 亦列於表 4，此等與實際達到 50% 始蘗期發育速率 (= 1) 皆相當接近；最後估算每次執行驗證程序所得預測與實際發育速率間的差異 (即預測誤差)，各生育階段 3 個品種所有執行次數所得預測誤差的 95% CI 皆含 0 在內，表示利用 GDD 預測此 3 個品種之 50% 始蘗期、幼穗分化期及 50% 抽穗期的誤差在 5% 水準下與 0 無顯著差異，皆在可接受範圍內 (表 4)。

因此，將 3 個品種所有年期試驗資料再合併進行 GDD 預測模式建立，線性關係配適圖如圖 1，所得分析結果整理如表 5，各品種各

表 1. 「台稉 9 號」水稻品種 2006–2008 及 2010 年於不同期作及插秧日期下各生育階段的生育日數與生育度數 (GDDs)。

Table 1. The calendar days and growing degree days (GDDs) to different growth stages of 'TK9' rice variety planted at different transplanting dates in a two-crop system in 2006–2008 and 2010.

Year	Crop season	Transplanting date	Transplanting to 50% tillering		50% tillering to panicle initiation		Panicle initiation to 50% heading	
			Days	GDD (℃)	Days	GDD (℃)	Days	GDD (℃)
2006	I	Feb. 21	19.0	189.2	40.3	508.7	20.0	320.1
	II	Aug. 10	10.3	196.6	36.3	655.1	19.0	318.1
2007	I	Feb. 13	18.3	201.5	44.0	524.1	21.0	314.2
	II	Aug. 10	14.7	253.3	34.7	619.2	21.3	350.9
2008	I	Feb. 19	23.7	242.7	38.7	585.6	21.7	320.3
	II	Aug. 11	12.7	244.9	36.0	664.5	18.3	309.8
2010	I	Jan. 20	21.7	227.8	43.0	448.7	28.0	340.8
		Feb. 04	26.3	253.1	39.7	455.6	23.7	323.7
		Feb. 23	20.3	249.9	38.3	463.8	21.3	313.9
		Mar. 05	18.7	213.3	40.0	488.8	21.3	338.5
	II	Jul. 07	14.3	277.2	40.0	752.2	16.3	309.7
		Jul. 23	12.7	232.7	37.3	702.2	17.0	303.5
		Aug. 10	12.3	245.9	36.3	652.9	18.0	316.4
		Aug. 20	11.7	215.9	43.3	777.2	21.3	299.8
Mean			16.9	232.9	39.1	592.8	20.6	320.0
SD[z]			4.9	25.4	2.9	112.2	3.0	14.5
CV(%)			29.0	10.9	7.4	18.9	14.6	4.5

[z] SD, standard deviation; CV, coefficient of variation.

生育階段之發育速率與 GDD 間的線性回歸式都極顯著存在 (F 檢定機率值皆 < 0.0001)，且模式都配適良好 (R^2 = 0.842–0.970)。各品種合併所有資料建模所得之截距與回歸係數 (表 5)，皆各落在前述多次模式驗證程序中所得截距與回歸係數之 95% CI 內 (表 4)，顯示此等 GDD 預測模式是穩健的。

由表 5 中 GDD 預測模式的回歸係數之大小，可發現插秧至 50% 始蘗期之回歸係數估值由大到小，依序為 'TNG22'、'TK9' 及 'TNG71'，表示在達到相同 GDD 下，'TNG22' 的生育速率最快，其次為 'TK9'，而 'TNG71' 最慢，即 3 個參試品種在插秧至 50% 始蘗期間的發育速率存在差異；而各品種在 GDD 預測模式中的截距項差異，則可反映出品種在秧苗時已存在的植株發育差異，由大而小依序分別為 'TNG71'、'TNGS22' 及 'TK9'。50% 始蘗期至幼穗分化期之 GDD 預測模式中的回歸係數由大到小，依序為 'TNG71'、'TK9' 及 'TNGS22'，表示在達到相同 GDD 下，'TNG71' 的生育速率最快，其次為 'TK9'，而 'TNGS22' 最慢；各品種在 GDD 預測模式中的截距項差異，則可呈現出品種先前在達到 50% 始蘗期時存在的植株發育情況差異，由大而小依序為 'TK9'、'TNG71' 及 'TNGS22'。幼穗分化期至 50% 抽穗期之 GDD 預測模式中的回歸係數，由大到小依序為 'TK9'、'TNG71' 及 'TNGS22'，顯示出達到相同 GDD 下，以 'TK9' 的發育速率最快，'TNG71' 次之，而 'TNGS22' 最慢；由模式中截距項差異，則可呈現出品種在達到幼穗分化期時已存在的植株發育情況差異，由大而小依序為 'TNG71'、'TK9' 及 'TNGS22'。

品種間各生育階段所需 GDD 之比較

利用上述合併所有試驗資料所建立的 3 個重要生育階段發育速率之 GDD 預測模式 (表

表 2. 「台農 71 號」水稻品種 2006–2010 年於不同期作及插秧日期下各生育階段的生育日數與生育度數 (GDDs)。

Table 2. The calendar days and growing degree days (GDDs) to different growth stages of 'TNG71' rice variety planted at different transplanting dates in a two-crop system in 2006–2010.

Year	Crop season	Transplanting date	Transplanting to 50% tillering		50% tillering to panicle initiation		Panicle initiation to 50% heading	
			Days	GDD (℃)	Days	GDD (℃)	Days	GDD (℃)
2006	I	Feb. 21	17.0	166.4	40.7	505.4	18.0	282.6
	II	Aug. 10	12.3	233.5	29.0	525.7	23.3	405.1
2007	I	Feb. 13	16.3	184.9	42.0	477.1	20.3	318.3
	II	Aug. 10	11.7	200.2	32.7	579.9	18.7	329.6
2008	I	Feb. 19	21.3	211.4	36.3	542.3	20.7	291.8
	II	Aug. 11	12.0	232.1	30.7	569.9	19.7	328.7
2009	I	Feb. 04	14.7	173.6	45.3	514.2	23.0	300.8
		Feb. 19	14.0	174.1	45.3	523.9	20.3	291.9
		Mar. 05	14.7	145.7	38.0	472.8	19.7	291.7
	II	Jul. 07	13.0	255.5	36.3	700.6	16.3	338.1
		Jul. 23	10.3	205.7	38.0	733.5	16.3	332.9
		Aug. 10	11.3	216.9	31.0	615.1	17.3	323.0
		Aug. 23	12.7	253.3	32.7	619.0	21.7	344.0
2010	I	Jan. 20	19.3	196.8	49.0	514.3	23.7	303.2
		Feb. 04	24.3	223.6	42.0	515.1	23.3	323.7
		Feb. 23	21.7	263.6	39.3	450.7	18.3	277.4
		Mar. 05	17.3	193.3	40.3	493.3	18.0	301.0
	II	Jul. 07	15.7	302.2	34.3	648.7	17.3	311.4
		Jul. 23	12.3	226.6	34.0	640.5	18.0	323.6
		Aug. 10	12.0	226.6	34.3	623.8	17.3	318.8
		Aug. 20	14.0	258.4	37.3	668.5	25.0	372.8
Mean			15.1	216.4	37.5	568.3	19.8	319.5
SD[z]			3.8	37.7	5.3	80.1	2.6	30.0
CV(%)			25.2	17.4	14.1	14.1	13.1	9.4

[z] SD, standard deviation; CV, coefficient of variation.

5)，可反推得到達到各生育階段所需之 GDD 如表 6。由此發現，各品種達到 3 個不同生育階段 (50% 始蘗期、幼穗分化期及 50% 抽穗期) 所需 GDD 有所不同：相對於其他品種，'TNGS22' 在插秧至 50% 始蘗期所需的 GDD 較低，但之後 50% 始蘗期至幼穗分化期、幼穗分化期至 50% 抽穗期所需 GDD 都較高；'TNG71' 與 'TK9' 在插秧至 50% 始蘗期所需 GDD 較高且兩者極為相近 (僅差 3.4℃)，但 50% 始蘗期至幼穗分化期所需 GDD 以 'TNG71' 最低，而幼穗分化期至 50% 抽穗期所需 GDD 則 'TNG71' 與 'TK9' 兩個品種又相近 (僅差 7.5℃)。若以插秧後開始累積至幼穗分化期所需 GDD 來看，由多至少依次為 'TNGS22'、'TK9' 及 'TNG71'，由插秧後直至 50% 抽穗期所需 GDD，由多至少依次也是 'TNGS22'、'TK9' 及 'TNG71'，故無法得知 3 個參試品種間在不同生育階段所需 GDD 之實際差異變化。因此，本研究將插秧至 50% 始蘗期、50% 始蘗期至幼穗分化期、幼穗分化期至 50% 抽穗期以分段方式來分別建立其 GDD 預測模式，並推估達到該等生育階段所

表 3. 「台農秈 22 號」水稻品種 2006–2010 年於不同期作及插秧日期下各生育階段的生育日數與生育度數 (GDDs)。

Table 3. The calendar days and growing degree days (GDDs) to different growth stages of 'TNGS22' rice variety planted at different transplanting dates in a two-crop system in 2006–2010.

Year	Crop season	Transplanting date	Transplanting to 50% tillering		50% tillering to panicle initiation		Panicle initiation to 50% heading	
			Days	GDD (℃)	Days	GDD (℃)	Days	GDD (℃)
2006	I	Feb. 21	18.7	182.5	49.0	640.5	24.7	399.5
	II	Aug. 10	9.3	178.1	36.7	662.2	24.0	404.0
2007	I	Feb. 13	18.3	200.7	50.0	611.2	23.3	374.6
	II	Aug. 10	9.7	166.6	39.0	693.5	20.7	324.7
2008	I	Feb. 19	23.0	234.0	46.3	683.3	25.3	406.2
	II	Aug. 11	9.7	186.7	39.0	722.7	20.7	345.7
2009	I	Feb. 04	17.0	204.0	54.3	626.8	24.0	337.0
		Feb. 19	11.7	150.1	54.0	635.9	23.7	343.7
		Mar. 05	14.3	136.4	47.7	611.6	23.3	376.8
	II	Jul. 07	11.7	228.8	43.7	846.6	17.7	357.5
		Jul. 23	9.0	177.7	44.3	861.0	17.3	344.2
		Aug. 10	10.7	204.1	38.0	747.9	21.0	326.8
		Aug. 23	9.3	186.1	36.3	691.2	23.7	357.5
2010	I	Jan. 20	19.3	196.8	61.0	657.6	26.0	354.0
		Feb. 04	25.3	238.6	52.7	623.1	21.0	313.9
		Feb. 23	18.0	216.7	48.7	600.5	22.7	368.8
		Mar. 05	19.0	215.7	50.0	656.6	22.7	256.9
	II	Jul. 07	14.0	270.8	41.0	771.3	21.0	381.3
		Jul. 23	11.7	213.5	40.0	751.4	19.3	342.2
		Aug. 10	10.3	194.5	40.3	735.3	19.3	330.7
		Aug. 20	10.3	193.5	41.3	739.2	23.7	343.2
Mean			14.3	198.8	45.4	693.8	22.1	351.9
SD[z]			4.9	30.5	6.8	74.1	2.4	34.0
CV(%)			34.3	15.3	15.0	10.7	10.9	9.7

[z] SD, standard deviation; CV, coefficient of variation.

需 GDD，以獲得較多訊息。

再從圖 2 中各品種達到各生育階段 (50% 始櫱期、幼穗分化期及 50% 抽穗期) 之前的發育速率與 GDD 之變化趨勢來看，自插秧後最初發育速率由快至慢依次為 'TNG71'、'TNGS22' 及 'TK9'，直到 GDD 約 60℃ 時 'TNGS22' 發育速率開始超過 'TNG71'，隨著 GDD 累積，'TNGS22' 發育速率越快，先達到 50% 始櫱期，故 'TNGS22' 達到 50% 始櫱期所需 GDD 最低；從 50% 始櫱期後，'TNGS22' 發育速率開始變緩而慢於其他兩品種，而約在 GDD = 200℃時，'TNG71' 發育速率超過 'TK9'，且隨著 GDD 累積，'TNG71' 與 'TK9' 間的發育速率差異就越大，最後 'TNG71' 先達到幼穗分化期，故 'TNG71' 由 50% 始櫱期至幼穗分化期所需 GDD 最低；從幼穗分化期後，隨著 GDD 累積，'TNGS22' 發育速率越慢於其他兩品種，在此生育階段期間內 'TK9' 與 'TNG71' 發育速率相當接近，最後皆先達到 50% 抽穗期，而以 'TNG71' 稍晚於 'TK9'，故 'TK9' 與 'TNG71' 在此期間所需 GDD 最低，而 'TNG71' 又略高於 'TK9'，但兩者差異甚

表 4. 三個水稻品種之生育度數 (GDDs) 生育階段預測模式進行內部驗證之結果。

Table 4. Results of internal validation of growing degree days (GDDs) models for predicting growth stages in three rice varieties.

		Estimated coefficients of linear model[y]		Prediction of development rate (d^{-1})	
Growth stage/Variety	95% CI[z]	b_0	b_1	Pred. value	Pre. error
Transplanting to 50% tillering					
TK9	Lower limit	0.02420	0.00405	0.93	-0.07
	Upper limit	0.02792	0.00421	1.06	0.06
TNG71	Lower limit	0.07457	0.00397	0.86	-0.14
	Upper limit	0.07907	0.00403	1.02	0.02
TNGS22	Lower limit	0.04740	0.00451	0.88	-0.12
	Upper limit	0.05146	0.00455	1.01	0.01
50% tillering to panicle initiation					
TK9	Lower limit	0.08439	0.00143	0.84	-0.16
	Upper limit	0.09013	0.00145	1.04	0.04
TNG71	Lower limit	0.04886	0.00162	0.91	-0.09
	Upper limit	0.05074	0.00164	1.03	0.03
TNGS22	Lower limit	0.03793	0.00136	0.94	-0.06
	Upper limit	0.03949	0.00138	1.04	0.04
Panicle initiation to 50% heading					
TK9	Lower limit	0.01047	0.00305	0.97	-0.03
	Upper limit	0.01259	0.00308	1.02	0.02
TNG71	Lower limit	0.02361	0.00294	0.92	-0.08
	Upper limit	0.02547	0.00297	1.01	0.01
TNGS22	Lower limit	0.00926	0.00272	0.93	-0.07
	Upper limit	0.01155	0.00274	1.02	0.02

[z] CI, confidence interval.

[y] b_0 and b_1 indicate the intercept and regression coefficient in linear model using training dataset in internal validation, respectively.

微。由此可知，3 個品種皆為中晚熟品種，但 ‘TNG71’ 由於在 50% 始蘗期至幼穗分化期之間的發育速率較快，而呈現稍早熟；‘TNGS22’ 雖於插秧至 50% 始蘗期之間的發育速率較快，但自 50% 始蘗期以後到 50% 抽穗期的發育速率變慢，以致呈現稍晚熟。

討論

本研究經多年期試驗調查結果，發現 ‘TK9’、‘TNG71’ 及 ‘TNGS22’ 3 個水稻品種於 3 個特定生長發育階段所需 GDD 在不同年期間的變異，大致上皆小於生育日數之年期變異 (表 1–3)，此與前人研究針對其他水稻品種所得 GDD 在不同年度間差異不大之結論相當一致 (Wilson *et al*. 2005; Frizzell *et al*. 2010)，顯示相較於生育日數，以 GDD 建立模式當可較不受氣候環境影響，而更能精準預測水稻生育階段。本研究藉由內部驗證程序，顯示使用 GDD 預測 3 個品種於 3 個生育階段的發育速率誤差皆在可接受的 5% 顯著水準範圍內 (表 4)。因此，合併所有試驗資料建立 3 個品種之 3 個生育階段的 GDD 預測模式，其回歸係數也都落在前述驗證程序所得模式之截距與回歸係數的 95% CI 之內，顯示此等 GDD 預測模式是穩健的 (表 5)。由此可推得 3 個品種從插秧至 50% 始蘗期、50% 始蘗期至幼穗分化期、幼穗分化期至 50% 抽穗期之各分段生育期所需的積溫 (表 6)。依據各生育階段之 GDD 預測模式的回歸係數 (表 5) 或所需 GDD (表 6)

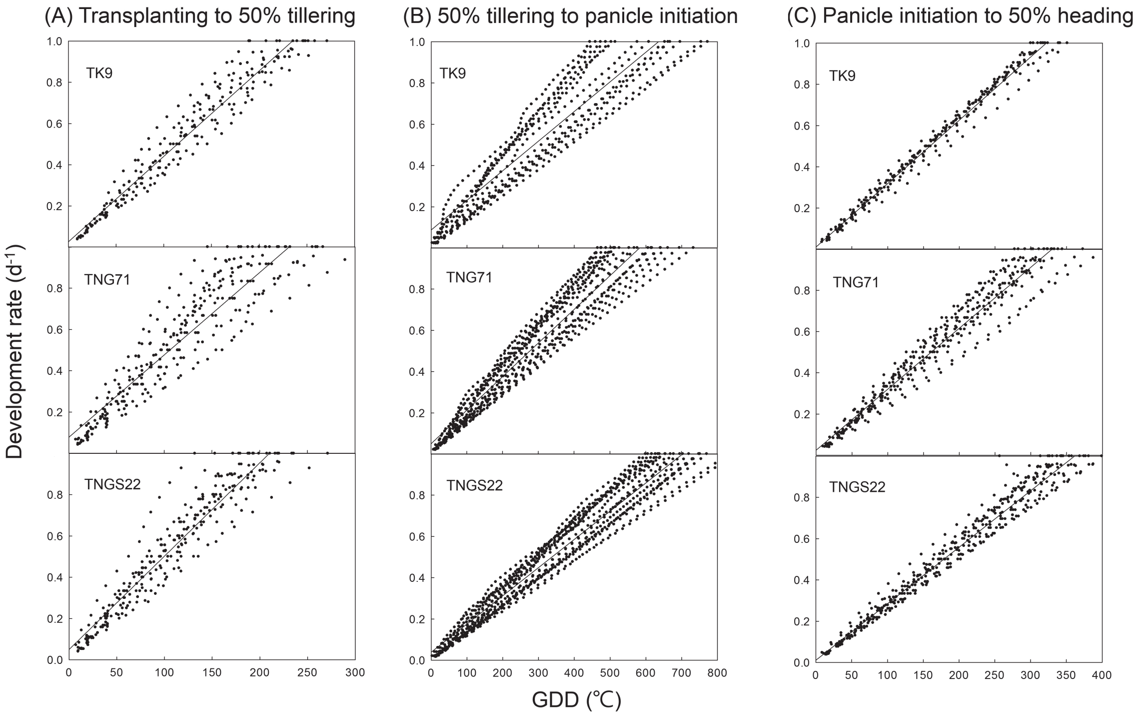

圖 1.　三個水稻品種於不同生育階段的發育速率與生育度數 (GDDs) 之線性關係配適圖。(A) 插秧至 50% 始蘗期；(B) 50% 始蘗期至幼穗分化期；(C) 幼穗分化期至 50% 抽穗期。

Fig. 1.　Curve fitting diagrams showing the linear relationships between development rates and growing degree days (GDDs) for different growth stages in three rice varieties. (A) Transplanting to 50% tillering; (B) 50% tillering to panicle initiation; and (C) panicle initiation to 50% heading.

表 5.　三個水稻品種利用所有試驗資料所建立之生育度數 (GDDs) 生育階段預測模式。

Table 5.　The growing degree days (GDDs) models for predicting growth stages in three rice varieties based on pooled data sets.

Growth stage/Variety	b_0^z	b_1	R^2	Pr < F
Transplanting to 50% tillering				
TK9	0.02619	0.00415	0.939	< 0.0001
TNG71	0.07707	0.00399	0.842	< 0.0001
TNGS22	0.04954	0.00453	0.900	< 0.0001
50% tillering to panicle initiation				
TK9	0.08769	0.00144	0.851	< 0.0001
TNG71	0.04992	0.00163	0.916	< 0.0001
TNGS22	0.03878	0.00137	0.943	< 0.0001
Panicle initiation to 50% heading				
TK9	0.01159	0.00307	0.986	< 0.0001
TNG71	0.02464	0.00296	0.944	< 0.0001
TNGS22	0.01059	0.00274	0.970	< 0.0001

[z] b_0 and b_1 indicate the intercept and regression coefficient in linear model, respectively; R^2, coefficient of determination; Pr < F, probability of F test.

表 6. 三個水稻品種經由模式預測所推估達到不同生育階段所需的生育度數 (GDDs)。

Table 6. The growing degree days (GDDs) needed to reach different growth stages in three rice varieties using model prediction.

Variety	Transplanting to 50% tillering	50% tillering to panicle initiation	Panicle initiation to 50% heading	Transplanting to panicle initiation	Transplanting to 50% heading
TK9	234.7	633.6	322.0	868.3	1190.3
TNG71	231.3	582.9	329.5	814.2	1143.7
TNGS22	209.8	701.6	361.0	911.4	1272.4

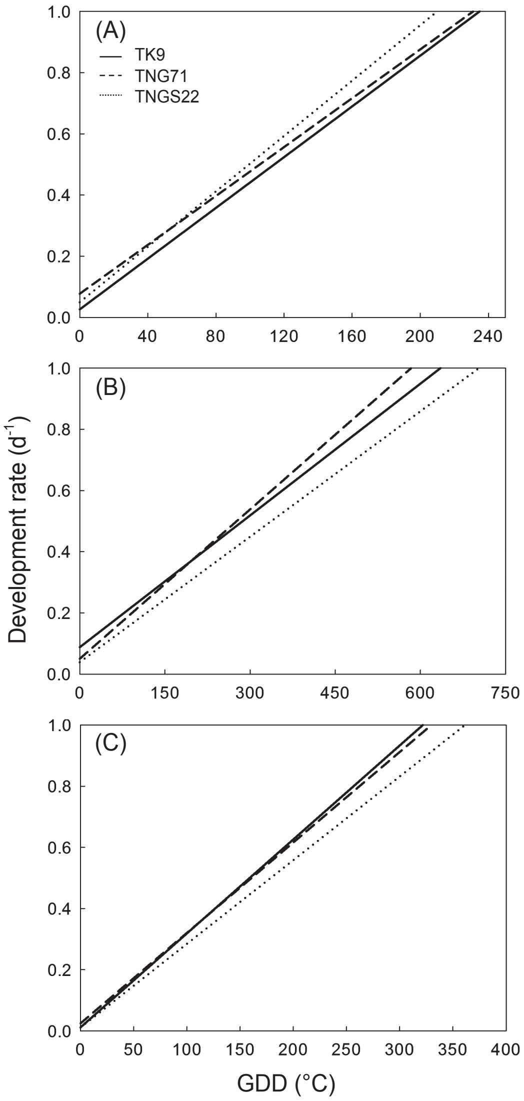

圖 2. 三個水稻品種各生育階段期間內發育速率與生育度數 (GDDs) 之變化趨勢的比較。(A) 插秧至 50% 始蘗期；(B) 50% 始蘗期至幼穗分化期；(C) 幼穗分化期至 50% 抽穗期。圖中趨勢線爲經由 GDD 模式所估得。

Fig. 2. Comparison of the changes of growing degree days (GDDs) and development rates during the periods of different growth stages among rice varieties. (A) Transplanting to 50% tillering; (B) 50% tillering to panicle initiation; and (C) panicle initiation to 50% heading. The trend lines are estimated from GDD models.

的大小，以及 3 個品種達到各生育階段前的發育速率與 GDD 之變化趨勢 (圖 2)，皆可發現不同品種在各生育階段的發育速率不盡相同，由此可用以解釋 3 個品種雖皆為中晚熟品種，但 ‘TNG71’ 稍早熟而 ‘TNGS22’ 稍晚熟，係因 ‘TNG71’ 在 50% 始蘗期至幼穗分化期間的發育速率較快，而 ‘TNGS22’ 在插秧至 50% 始蘗期間雖發育速率較快，但之後到 50% 抽穗期間發育速率變慢所致。

水稻發育自插秧至幼穗分化期為營養生長期，幼穗分化期至 50% 抽穗期為生殖生長期，此兩時期的發育速率已知未必相同 (Yoshida 1981; Horie & Nagakawa 1990)。為提升稻穀產量，應依照不同品種於其關鍵生育階段實施適當的栽培管理，例如從始蘗期至分蘗盛期再到幼穗分化期，宜開始追加氮肥與鉀肥 (Yoshida 1981; Bollich *et al*. 1999)；由於幼穗分化為一穗粒數、雄蕊及雌蕊形成的重要生育時間點 (Matsushima 1980; Chiu 1993; Bollich *et al*. 1999)，幼穗分化期宜多施穗肥 (氮肥) 以增加產量 (Yoshida 1981; Slaton & Norman 1994; Bollich *et al*. 1999)；此外，幼穗分化期及抽穗期的抽穗、開穎及授粉，也需要施以較多水分 (Bollich *et al*. 1999)。本研究結果得知，由於 ‘TK9’、‘TNG71’ 及 ‘TNGS22’ 3 個國內重要中晚熟品種在各生育階段的發育速率不盡相同，故達到 50% 始蘗期、幼穗分化期及 50% 抽穗期的時間並不相同，因此應配合其關鍵生育階段施以適當的肥培與水份管理。

本研究 3 個品種在 3 個生育階段的 GDD 預測模式，經回歸式顯著性及 R^2 值來判斷，皆配適良好 (表 5)，但從發育速率與有效積溫之線性關係配適圖 (圖 1) 而言，發現似乎有些品種在 50% 始蘗期與幼穗分化期，隨著 GDD 越高，發育速率的變異越大，意味著該回歸模式可能存在統計上的缺適性 (lack of fit)。一般而言，直線回歸分析存在缺適性問題時，表示試驗資料可能不符合回歸模式的 3 個重要基本假設：殘差 (residue) 要符合獨立性 (independence)、常態性 (normality) 及變方同質性 (homoscedasticity)；對於缺適性若疏忽不處理，所得線性關係之推論將可能產生誤導或無效，但可藉由用殘差分析之缺適性檢定方法，來顯示模式是否需要轉換或修正 (Kutner *et al*. 2004; Montgomery 2009)。針對本研究 3 個品種分別達 50% 始蘗期與幼穗分化期的 GDD 預測模式，經缺適性檢定結果，發現只有 ‘TNG71’ 及 ‘TNGS22’ 達 50% 始蘗期的 GDD 預測模式存在顯著的缺適性，因此將此部份試驗資料之發育速率透過 BOX-COX 轉換法 (Kutner *et al*. 2004)，得到最大對數概度值 (maximum log likelihood) 以選取適當的冪次 (exponentiation) 數值進行轉換；資料經冪次轉換後所建立的 GDD 預測模式：‘TNG71’ 為 Y = 0.11649 + 0.00388X，‘TNGS22’ 為 Y = 0.09009 + 0.00439X，以此估計所需 GDD 各為 227.7℃及 207.3℃，此與原來未經轉換的兩個 GDD 預測模式 (表 5：‘TNG71’ 為 Y = 0.07707 + 0.00399X，‘TNGS22’為 Y = 0.04954 + 0.00453X) 及其估得之所需 GDD (表 6：‘TNG71’ 及 ‘TNGS22’ 各為 231.3℃及 209.8℃) 相比較，回歸係數相近並仍落在多次模式驗證執行程序之所得回歸係數的 95% CI 之內 (表 4)，且預估所需 GDD 亦相差甚小，因此判斷 ‘TNG71’ 及 ‘TNGS22’ 兩品種達 50% 始蘗期的 GDD 預測模式建立並不受缺適性所影響。

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Establishment and Validation of Prediction Model for Rice Growth Stages

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Abstract

Lin, S. H., C. T. Lu, W. S. Jwo, and H. Y. Lu. 2014. Establishment and validation of prediction model for rice growth stages. J. Taiwan Agric. Res. 63(1):30–42.

The aim of this study is to establish the models for predicting three major growth stages (i.e., 50% tillering, panicle initiation, and 50% heading) of three mid-late maturing Taiwan rice varieties (i.e., 'TK9', 'TNG71', and 'TNGS22'). Data sets were collected from the field experiments of rice varieties planted at various transplanting dates in a two-crop system in 2006–2010. For every growth stage of each variety, a linear regression model for predicting growth stage was established using daily development rate during the period as the dependent variable and its corresponding daily effective accumulated temperature (growing degree days; GDD) as the independent variable. The predictive capability of GDD model was tested by internal validation. It showed that all the 95% confidence intervals (CI) of the differences between predicted and actual values of development rate included zero, which reveals an acceptable predictive error at 5% significance level. Then, all data sets were pooled to build up the GDD models for predicting growth stage. The estimated values of intercept and regression coefficient in these GDD models were within the 95% CI of those estimated values obtained from above validation procedures. Results suggest that the established GDD models for predicting rice growth stages are robust. With these models, GDDs need to reach each growth stage in three rice varieties could be estimated. Results also indicated that these three rice varieties were not completely identical in development rates during the periods of different growth stages. Although they are mid-late maturing varieties, the sequence of full maturity for these three mid-late maturing varieties is in the order of 'TNG71', 'TK9', and 'TNGS22'. It was due to the growth of 'TNG71' was faster during the period from 50% tillering to panicle initiation, while the growth of 'TNGS22' was slower during the period from 50% tillering to 50% heading in spite of rapid growth before 50% tillering. Therefore, to increase paddy yield, proper field management should be arranged in critical growth stages in respective rice varieties.

Key words: Effective accumulated temperature, Growing degree days, Linear regression model, Development rate, Predictive error.

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荔枝新品種「台農 7 號 (早大荔)」之育成

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摘要

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新品種荔枝「台農7號 (早大荔)」係農業試驗所嘉義分所自 1982 年以「沙坑」為母本之實生後裔選育而得，於 2010 年取得品種權。本品種兼具早熟、大果特性，故以此命名。「台農 7 號 (早大荔)」於台灣南部地區可於 5 月上旬至下旬採收，較早熟商業品種「玉荷包」早約 10 d，較中熟商業品種「沙坑」或「黑葉」早約 17–21 d。本品種生產栽培成本低於「玉荷包」，而單穗著果量與豐產品種「沙坑」及「黑葉」相當，品種系比較試驗及區域試驗結果亦顯示本品種著果良好且無明顯隔年結果；「台農 7 號 (早大荔)」果實平均單果重約 25–35 g，果色澤紅、果形呈橢圓或心形、清甜多汁，具備市場價值，期能部分取代我國現有荔枝生產，提早荔枝產期，紓解台灣長期以來的荔枝產銷問題。

關鍵詞：台灣、荔枝育種、玉荷包、黑葉、沙坑。

前言

荔枝 (*Litchi chinensis* Sonn.) 爲台灣近 10 年栽培面積第 4 大果樹作物，佔台灣果樹栽培面積 5.7%，僅次於柑橘類、檳榔及香蕉，近 5 年平均年產值近新台幣 31 億元，顯示其在台灣果樹產業的重要性。目前台灣荔枝栽培品種仍以「黑葉」爲主，約佔總栽培面積 70% (Lee *et al*. 2010; Chang *et al*. 2012)，產期集中加上「黑葉」荔枝不耐貯存 (Yeh *et al*. 2013)，時有產銷失衡減損農友收益情形，在中部地區尤甚。南部地區荔枝果實成熟期較早，部分果農種植市場價格較高的早熟品種「玉荷包」荔枝，可分散市場供給、紓緩滯銷問題。然而，近年來「玉荷包」栽植面積已增加至近3,000 ha (Hsu 2008)，栽培技術較爲繁瑣、每公斤生產成本約新台幣 33–50 元 (Chang *et al*. 2012)，高於其他商業品種。而且台灣過去 10 年「玉荷包」年市場均價兩度跌破新台幣 50 元 (2007 年「玉荷包」年市場均價爲新台幣 47.2 元、2009 年爲新台幣 47.4 元)，顯示「玉荷包」已面臨產銷不穩定的局面。如何調整產業結構，健全產業經營與發展，已然是台灣荔枝產業一大考驗。

開發加工、貯藏技術可以延長果實供貨時程、擴大市場，然而寄望果品得以提早上市以調整生產結構，迄今仍仰賴荔枝育種選拔。行政院農業委員會農業試驗所自 2005 年起分別選育出「台農 1 號 (翠玉)」(Chang *et al*. 2005)、「台農 2 號 (旺荔)」(Teng & Liu 2007)、「台農 6 號 (豔荔)」(Teng & Chen 2011) 等品質優良的早熟品種荔枝，各該品種獨具特色，備受期盼能部分取代「玉荷包」及「黑葉」在台灣荔枝產業所佔區位，以增進產業價值。兼具果色鮮紅、果實碩大、豐產而穩定等品種特色，

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乃是荔枝育種者追求的目標之一 (Sarin *et al*. 2009)，而且在荔枝產業轉型與佈局之初面對多元市場需求，亦較易有出線機會。本研究以選育早熟大果、穩產豐產、易於栽培管理品種且具市場獨特性爲育種目標，選育出「台農 7 號 (早大荔)」荔枝，本文說明自選拔至各階段試驗評估之育成歷程，而該品種由於果實大、產期早於「玉荷包」具市場優勢，遂得其名。

材料與方法

育種方法與程序

本品種選育溯自 1982 年，係先以多交方式 (poly cross) 取得種子，母本爲農業試驗所嘉義農業試驗分所荔枝遺傳資源庫中的「沙坑」，園區尚植有「玉荷包」與「黑葉」荔枝。種子於當年培育爲實生苗後定植於嘉義分所試驗果園，歷經實生苗選拔、品種系比較試驗、區域試驗及植物性狀檢定等程序，於 2010 年 12 月獲得農業委員會果樹品種審議委員會審核通過、取得品種權。

實生苗培育與選拔

1983 年將前年度培育之實生苗以 2.5 m × 0.5 m 行株距密植於嘉義分所試驗果園，並依一般荔枝栽培及病蟲害防治方式管理園區。實生苗於 1987 年起陸續開花結果，分別於 1987 年評估 39 個品系，1988 年評估 50 品系。以單果重 20 g 以上、具有焦核、可溶性固形物在 16°Brix 以上，果實成熟期異於「黑葉」等條件列爲選拔標準，評選出品質較優良者共 12 品系，其中包含品系代號 ‘71-3-15’ 實生苗 [即爲本品種「台農 7 號 (早大荔)」，於下以後者名之]。

品種系比較試驗

具有優良性狀的「台農 7 號 (早大荔)」實生苗與對照品種「黑葉」於 1987 年進行品種系比較試驗，二者經高壓法無性繁殖後擇定 5 株，以 4 m × 3 m 行株距栽植於嘉義分所試驗果園，並按一般荔枝栽培方法管理園區。同年並取相鄰之分所荔枝品種園「沙坑」之高壓苗 5 株，株齡爲 9 年、行株距 4 m × 3 m，作爲參考對照品種。2000–2004 年度各荔枝著果期間調查果實性狀，依 Chang *et al*. (2010) 所敘方法調查包括果實單果重、果皮重、果肉重、種子重、焦核率、可溶性固形物含量、可滴定酸及結果數等項目。

區域試驗

「台農 7 號(早大荔)」與對照商業品種「玉荷包」於台南市楠西區、屏東縣高樹鄉、高雄市杉林區 3 處篤實農戶荔枝園進行區域試驗。台南試區於 1999 年以高壓苗作爲試驗材料、行株距 4 m × 4 m，兩品種系逢機取 5 株，自 2003 年開始調查果實性狀。屏東試區自 1999 年以 10 年生「黑葉」高壓苗爲砧木，採嫁接株作爲試驗材料進行試驗，供試品種系皆爲 5 株，2003 年起調查果實性狀。高雄試區於 2005 年採以 5 年生「玉荷包」爲砧木之「台農 7 號 (早大荔)」嫁接株及未嫁接者作爲試驗材料進行試驗，各供試品種系同爲 5 株，2008 年起調查果實性狀。區域試驗中，果實性狀調查方式與品種系比較試驗相同。

植物性狀檢定

根據「植物品種及種苗法」(第六版，2010)，申請植物品種權時須塡寫植物品種性狀檢定報告書，以證明申請品種與對照品種具有可區別性。「台農 7 號 (早大荔)」整體植物性狀與其母本「沙坑」最爲接近。2008–2010 年間於嘉義農業試驗分所以「沙坑」作爲對照品種檢定「台農 7 號 (早大荔)」，植物性狀檢定項目參照臺灣現有作物栽培品種名錄 (Chao 1999) 及農業委員會農糧署公告之荔枝品種性狀檢定表 (test guideline) 爲之。

資料分析

本研究採完全逢機設計，試驗資料經由 Microsoft Excel 2007 套裝軟體 (Microsoft Corporation, Washington, USA) 或 SAS 9.0 套裝軟體套裝軟體 (SAS Institute Inc., North Carolina, USA) 進行變方分析 (one way ANOVA)，以及最小顯著差異性測驗 (Fisher’s least significant difference; LSD)、*t* 檢定 (Student’s *t*-test) 比較。

結果

實生苗初選

1987–1988 年兩度評估實生苗，‘71-3-15’ 即「台農 7 號 (早大荔)」，穩定表現早熟大果的特性 (表 1)：包含平均單果重約 27 g，種子重約 4.5 g，平均果肉率在 64.4–67.6% 間，可溶性固形物約 16.1°Brix 等，合乎選拔標準。

品種系比較試驗

2000–2004 年連續 5 年在嘉義分所品種系比較試驗結果 (表 2)，除 2002 年適逢乾旱年，根據中央氣象局台灣南區氣象中心 (http://south.cwb.gov.tw/index1.php) 資料，當年 2–4 月份嘉義地區總雨量不及 5 mm，3 個供試品種系各項調查數值均明顯較其他年度低外，其餘 4 年間「台農 7 號 (早大荔)」平均果重介於 25–32 g，果皮重介於 4–6 g，果肉重介於 18–25 g，種子重介於 2.3–3.7 g (表 2)。「台農 7 號 (早大荔)」平均果重及果肉重於各年度內均顯著重於「黑葉」及「沙坑」，果皮及種子重量亦有高於「黑葉」及「沙坑」態勢。「台農 7 號 (早大荔)」果肉率介於 72–78% 間，與「黑葉」及「沙坑」相近；然而「台農 7 號 (早大荔)」與「沙坑」偶見焦核種子，前者焦核率介於 13–50% 間，後者介於 6–31% 間，焦核率並不穩定，「黑葉」則無焦核情形。在可溶性固形物含量方面，「台農 7 號 (早大荔)」與「黑葉」差異不大，約為 16–18°Brix 間，「沙坑」相對較低約為 15–16°Brix。「台農 7 號 (早大荔)」果皮顏色為淺紅至紅色，色澤較「黑葉」及「沙坑」鮮明。就著果情形而言，「台農 7 號 (早大荔)」於採收時平均每穗著生 8–13 顆果實，略高於「黑葉」之 6–11 顆及「沙坑」之 6–7 顆。「台農 7 號 (早大荔)」採收期約在 5 月 20 日至 5 月 29 日左右，較 6 月中旬採收之「黑葉」早約 17–24 d、較「沙坑」早約 17–21 d。

由於試區缺乏完善灌溉設備，2002 年乾旱影響 3 品種系荔枝果實生育，其中「黑葉」受乾旱影響最為明顯，平均果重約只有其他年份的 70%，而「台農 7 號 (早大荔)」及「沙坑」在該年果重則約為其他年份 85%。3 品種系荔枝果重下降係反映自果肉重降低，在「台農 7 號 (早大荔)」及「黑葉」亦可觀察到果肉率下降。

區域試驗

高樹試區試驗：屏東高樹試區「台農 7 號 (早大荔)」平均單果重介於 28–36 g 間、果皮重介於 3.5–6.0 g 間，種子重約 3–4 g，果肉率約 70–75%，焦核率介於 11–23% 之間，可溶性固形物含量約 16–17°Brix。「台農 7 號 (早大荔)」單果重、果肉重、種子重顯著較「玉荷包」高，果肉率、焦核率及可溶性固形物則反之 (表 3)。此外，「台農 7 號 (早大荔)」平均每穗可收穫 8–13 顆果實，約為「玉荷包」2 倍，而其採收日期為 5 月 9 日至 5 月 19 日，亦較「玉荷包」早 5–17 d。

楠西試區試驗：在台南楠西試區「台農 7 號 (早大荔)」性狀表現穩定，平均單果重約 28 g、果皮重約為 4–5 g、果肉重約為 21–22 g、種子重約為 3 g，果肉率約為 74%，焦核率約 10%，可溶性固形物含量約 16°Brix。「台農 7 號 (早大荔)」單果重及種子重顯著較「玉荷包」重，果肉率、焦核率及可溶性固形物含量則較「玉荷包」低 (表 4)。「台農 7 號 (早大荔)」平均每穗可收穫 8–10 顆果實，約為「玉荷包」2 倍，而其採收日期為 5 月 14 日至 5 月 31 日，亦較「玉荷包」早 7–13 d。

表 1. 1987 年至 1988 年「台農 7 號 (早大荔)」荔枝實生苗果實品質性狀與採收日期。

Table 1. Fruit characteristics and harvest dates of litchi seedlings ‘Tainung No.7 (Early Big)’ in 1987 and 1988[z].

Year	FW[y] (g)	AW (g)	SeW (g)	AP (%)	TSS (°Brix)	HD (mo. d)
1987	26.7	17.2	4.7	64.4	16.0	May 20
1988	28.7	19.4	4.3	67.6	16.1	May 24

[z] The materials for the trail were 5 year-old seedlings in 1987; data were mean of 20 fruit.
[y] Abbreviations, FW: fruit weight; AW: aril weight; SeW: seed weight; AP: aril percentage; TSS: total soluble solids content; HD: harvest date.

表 2.　嘉義農業試驗分所試區「台農 7 號 (早大荔)」荔枝及 2 比較品種果實性狀及採收期比較。

Table 2. Comparisons of fruit characteristics and harvest dates of litchi 'Tainung No.7 (Early Big)' and 2 companion cultivars tested at Chiayi Agricultural Experiment Branch of Taiwan Agricultural Research Institute[z].

Year	Cultivar	FW[y] (g)	PW (g)	AW (g)	SeW (g)	AP (%)	SS (%)	TSS (°Brix)	TA (%)	PC	Fruit no. $cluster^{-1}$	HD (mo. d)
2000	Tainung No. 7 (Early Big)	31.1 a[x]	5.2 a	22.7 a	3.2 a	73.3 a	23 a	18.1 a	0.23 a	red	9.0 a	May 26
	Hak Ip	23.7 b	3.5 b	17.7 b	2.5 a	74.6 a	0 b	16.0 b	0.05 b	dark red	6.0 b	June 17
	Sah Keng	23.4 b	3.9 b	17.3 b	2.3 a	73.5 a	14 ab	14.9 c	0.04 b	dark red	7.0 ab	June 12
2001	Tainung No. 7 (Early Big)	32.3 a	6.0 a	24.0 a	2.3 a	74.3 a	50 a	16.7 a	0.24 a	red	8.2 a	May 20
	Hak Ip	21.2 b	3.1 c	16.0 b	2.2 a	75.0 a	0 b	16.2 ab	0.09 b	dark red	5.3 a	June 12
	Sah Keng	23.7 b	4.0 b	17.2 b	2.4 a	72.9 a	0 b	15.0 b	0.13 ab	dark red	6.0 a	June 9
2002	Tainung No. 7 (Early Big)	25.6 a	4.1 a	18.4 a	3.1 a	72.0 b	13 a	18.7 a	0.08 b	red	13.4 a	May 24
	Hak Ip	16.7 c	2.4 b	11.9 c	1.8 b	73.9 b	0 b	18.0 a	0.19 a	dark red	9.3 ab	June 10
	Sah Keng	20.7 b	3.4 ab	15.9 ab	1.5 b	76.7 a	28 a	15.2 b	0.10 b	dark red	7.2 b	June 10
2003	Tainung No. 7 (Early Big)	31.7 a	4.1 a	24.5 a	3.1 a	77.6 a	15 ab	17.2 a	0.12 a	red	11.4 a	May 29
	Hak Ip	21.7 b	3.5 a	15.9 b	2.3 b	73.1 b	0 b	18.2 a	0.14 a	dark red	11.0 a	June 20
	Sah Keng	24.4 b	4.5 a	18.3 b	1.5 c	75.1 ab	31 a	18.3 a	0.12 a	dark red	6.8 b	June 17
2004	Tainung No. 7 (Early Big)	28.9 a	5.1 a	21.3 a	3.7 a	73.2 b	27 a	17.2 a	0.15 a	red	9.0 a	May 28
	Hak Ip	23.2 b	3.3 b	17.6 b	2.3 ab	75.8 ab	0 b	17.1 ab	0.10 a	dark red	6.6 a	June 21
	Sah Keng	23.2 b	3.7 b	17.5 b	1.8 b	76.4 a	6 ab	16.1 b	0.13 a	dark red	7.2 a	June 18

[z] The materials for the trail were 7-year-old air layers in 2000.
[y] Abbreviations, FW: fruit weight; PW: peel weight; AW: aril weight; SeW: seed weight; AP: aril percentage; SS: shriveled seed percentage; TSS: total soluble solids content; TA: titratable acidity; PC: peel color; Fruit no. $cluster^{-1}$: fruit number per cluster; HD: harvest date.
[x] Means followed by the same letters at the same column within the same year were not significantly different at 5% level by LSD test.

表 3. 屏東縣高樹試區「台農 7 號 (早大荔)」及「玉荷包」荔枝果實性狀及採收期比較。

Table 3. Comparisons of fruit characteristics and harvest dates of litchi ‘Tainung No. 7 (Early Big)’ and ‘Yu Her Pau’ at GauShu trial site in Kaohsiung City[z].

Year	Cultivar	FW[y] (g)	PW (g)	AW (g)	SeW (g)	AP (%)	SS (%)	TSS (°Brix)	TA (%)	PC	Fruit no. $cluster^{-1}$	HD (mo. d)
2003	Tainung No. 7 (Early Big)	30.3 a[x]	4.8 a	21.0 a	4.4 a	69.6 b	11 a	16.6 b	0.12 b	red	8.0 a	May 9
	Yu Her Pau	24.4 b	4.9 a	18.0 b	1.3 b	74.6 a	62 a	18.3 a	0.19 a	red with mild green	6.6 a	May 26
2004	Tainung No. 7 (Early Big)	27.7 a	4.0 a	20.7 a	3.0 a	75.0 a	23 b	17.4 a	0.10 a	red	9.2 a	May 12
	Yu Her Pau	1.8 b	3.7 a	16.6 a	1.5 b	76.2 a	60 a	17.6 a	0.10 a	red with mild green	4.0 b	May 27
2005	Tainung No. 7 (Early Big)	32.5 a	3.5 a	24.2 a	3.5 a	74.6 b	13 b	16.1 b	0.12 b	red	13.4 a	May 19
	Yu Her Pau	22.0 b	4.1 a	16.9 a	0.9 b	76.6 a	58 a	18.3 a	0.20 a	red with mild green	5.0 b	May 26
2006	Tainung No. 7 (Early Big)	35.6 a	6.1 a	25.8 a	3.9 a	73.1 b	14 b	16.4 b	0.15 a	red	10.0 a	May 12
	Yu Her Pau	23.8 b	3.5 b	19.4 b	0.9 b	81.4 a	60 a	17.6 a	0.10 b	red with mild green	4.0 b	May 17

[z] The materials for the trial were grafted in 1999, the root stocks were ‘Hak Ip’ air layers.

[y] Abbreviations, FW: fruit weight; PW: peel weight; AW: aril weight; SeW: seed weight; AP: aril percentage; SS: shriveled seed percentage; TSS: total soluble solids content; TA: titratable acidity; PC: peel color; Fruit no. $cluster^{-1}$: fruit number per cluster; HD: harvest date.

[x] Means followed by the same letters at the same column within the same year were not significantly different at 5% level by *t*-test.

表 4. 台南市楠西試區「台農 7 號 (早大荔)」及「玉荷包」荔枝果實性狀及採收期比較。

Table 4. Comparisons of fruit characteristics and harvest dates of litchi 'Tainung No. 7 (Early Big)' and 'Yu Her Pau' at Nansi trial site in Tainan City[z].

Year	Cultivar	FW[y] (g)	PW (g)	AW (g)	SeW (g)	AP (%)	SS (%)	TSS (°Brix)	TA (%)	PC	Fruit no. $cluster^{-1}$	HD (mo. d)
2003	Tainung No. 7 (Early Big)	28.3 a[x]	4.7 a	21.0 a	3.3 a	74.3 b	10 b	16.4 b	0.18 a	red	10.0 a	May 25
	Yu Her Pau	23.5 b	4.2 a	18.4 a	0.9 b	78.4 a	40 a	18.0 a	0.24 a	red with mild green	5.8 b	June 6
2004	Tainung No. 7 (Early Big)	27.8 a	3.9 a	20.4 a	3.5 a	73.6 b	6 b	16.0 b	0.13 b	red	8.2 a	May 14
	Yu Her Pau	24.9 b	4.4 a	19.6 a	0.8 b	78.8 a	58 a	17.7 a	0.27 a	red with mild green	4.6 b	May 27
2005	Tainung No. 7 (Early Big)	28.3 a	4.4 a	20.7 a	3.3 a	74.3 b	9 b	16.4 b	0.18 a	red	9.8 a	May 31
	Yu Her Pau	23.3 b	4.1 a	18.3 a	0.9 b	78.4 a	45 a	18.0 a	0.24 a	red with mild green	4.2 b	June 7

[z] The materials for the trail were 4 year-old air layers in 2003.

[y] Abbreviation, FW: fruit weight; PW: peel weight; AW: aril weight; SeW: seed weight; AP: aril percentage; SS: shriveled seed percentage; TSS: total soluble solids content; TA: titratable acidity; PC: peel color; Fruit no. $cluster^{-1}$: fruit number per cluster; HD: harvesting date.

[x] Means followed by the same letters at the same column within the same year were not significantly different at 5% level by *t*-test.

杉林試區試驗：高雄杉林試區「台農 7 號 (早大荔)」平均單果重約 33 g、果皮重約為 5 g、果肉重約為 24 g、種子重約 4 g，果肉率約 73%，焦核率為 10%，可溶性固形物含量約 16–17°Brix。「台農 7 號 (早大荔)」單果重、果肉重及種子重顯著較「玉荷包」重，果肉率、焦核率及可溶性固形物含量則較「玉荷包」低 (表 5)。「台農 7 號 (早大荔)」平均每穗可收穫 9–10 顆果實，較「玉荷包」平均 6–7 顆高，而其採收日期為 5 月 26 日至 5 月 27 日，較「玉荷包」早約 10 d。

「台農 7 號 (早大荔)」與「沙坑」植物性狀之差異性

「台農 7 號 (早大荔)」與「沙坑」重要植物性狀及差異性狀如表 6 所列，共具有 21 項性狀具可區別性，其中重要差異如下：(1) 葉片：「台農 7 號 (早大荔)」小葉葉形為長橢圓形、葉片較寬，因此小葉長/寬比值較低 (約 3.3)；「沙坑」小葉呈披針形、葉子較窄，葉長/寬比值較高 (約 4.3)。(2) 花：「台農 7 號 (早大荔)」花序長而疏，雌蕊柱頭形狀成微卷裂；「沙坑」花序短而密，雌蕊柱頭形狀為圓卷裂。(3) 果實：「台農 7 號 (早大荔)」果實成心形或橢圓形，果棘成毛尖狀，果皮色澤紅或淺紅色；「沙坑」果形為近圓球形，果棘乳頭狀突起，果皮顏色較暗紅。(4) 物候期：「台農 7 號 (早大荔)」小花約 2 月下旬陸續開放，果實在嘉義地區約於 5 月下旬成熟；「沙坑」小花於 3 月中旬陸續開放，果實在嘉義為 6 月中旬成熟。

討論

「台農 7 號 (早大荔)」選育始自 1982 年獲取種子至 2010 年取得品種權，共歷經 29 年。根據品種系比較試驗、區域試驗乃至於植物性狀檢定 (表 6) 一系列調查分析顯示「台農 7 號 (早大荔)」具有如下特性：(1) 新梢呈淡綠色 (圖 1A)。(2) 小葉形狀長橢圓形，葉片長寬比值約 3.3 (圖 1B)。(3) 花序長而分枝疏 (圖 1C)，雌蕊柱頭形狀成微卷裂 (圖 1D)。(4) 果實為心形或橢圓形 (圖 2A)，果皮色澤淡紅至紅，果棘毛尖 (圖 2B)，縫合線不明顯。(5) 平均果

表 5. 高雄市杉林試區「台農 7 號 (早大荔)」及「玉荷包」荔枝果實性狀及採收期比較。

Table 5. Comparisons of fruit characteristics and harvest dates of litchi 'Tainung No. 7 (Early Big)' and 'Yu Her Pau' at Shanlin trial site in Kaohsiung City[z].

Year	Cultivar	FW[y] (g)	PW (g)	AW (g)	SeW (g)	AP (%)	SS (%)	TSS (°Brix)	TA (%)	PC	Fruit no. cluster^{-1}	HD (mo. d)
2008	Tainung No. 7 (Early Big)	33.4 a[x]	4.7 a	24.4 a	4.3 a	73.1 b	10 b	16.7 b	0.05 a	red	10.0 a	May 26
	Yu Her Pau	25.3 b	4.8 a	19.3 b	1.1 b	76.4 a	44 a	18.5 a	0.09 a	red with mild green	7.0 b	June 6
2009	Tainung No. 7 (Early Big)	33.2 a	5.1 a	24.4 a	3.8 a	73.1 b	11 b	16.4 b	0.05 a	red	9.4 a	May 27
	Yu Her Pau	25.1 b	4.1 a	20.0 b	0.9 b	79.7 a	64 a	18.0 a	0.09 a	red with mild green	6.0 b	June 8

[z] 'Tainung No. 7 (Early Big)' was grafted in 2005, the root stocks were 8-year old 'Hak Ip' air layers. 'Yu Her Pau' were 8-year old air layers in 2005.

[y] Abbreviations, FW: fruit weight; PW: peel weight; AW: aril weight; SeW: seed weight; AP: aril percentage; SS: shriveled seed percentage; TSS: total soluble solids content; TA: titratable acidity; PC: peel color; Fruit no. cluster^{-1}: fruit number per cluster; HD: harvesting date.

[x] Means followed by the same letters at the same column within the same year were not significantly different at 5% level by *t*-test.

表 6. 「台農 7 號 (早大荔)」與「沙坑」荔枝物候期與植物性狀比較。

Table 6. Phenology and morphological characteristics of litchi 'Tainung No. 7 (Early Big)' and 'Sah Keng'[z].

Phenology and morphological characteristics	Tainung No. 7 (Early Big)	Sah Keng
Tree		
Crown shape	Dome shaped	Dome shaped
Trunk surface color	Brown	Brown
Tree growth habit	Spreading	Spreading
Leaf		
Leaflet number	3–4	3–4
Leaflet length (cm)	14.1 ± 0.9	12.2 ± 1.2
Leaflet width (cm)	4.3 ± 0.5	2.9 ± 0.2[y]
Length/width of leaflet	3.3 ± 0.3	4.3 ± 0.5
New leaflet color	Light green	Light green
Mature leaflet surface color	Dark green	Dark green
Leaflet blade shape	Long-elliptic	Lanceolate
Leaflet apex shape	Long-acuminate	Long-acuminate
Leaflet base shape	Broad-cuneate	Cuneate
Leaflet margin	Curling inward slightly	Entire
Flower		
Length of inflorescence (cm)	30.3 ± 3.9	17.3 ± 6.8
Flower bud density	Sparse	Dense
Split number of stigma	2	2
Attitude of splitting stigma	Arc-shaped	Rolling
Color of deteriorational stigma top	Yellow green	Red brown
Fruit		
Weight of per fruit (g)	29.6 ± 4.4	24.0 ± 0.9
Uniformity	uniform	uniform
Fruit shape	elliptic or cordate	Nearly globe-shaped
Mature fruit peel color	Bright red	Dark red
Fruit shoulders	Apophysis	Apophysis
Shape of protuberance	Sligytly pointed	Nipple-protruding
Presence of suture	Unobviously	Unobviously
Peel weight (g)	4.4 ± 0.8	3.5 ± 0.5
Color of aril	Waxy white	Waxy white
Aril texture	Soft	Soft
Aril juiciness	Very juicy	Very juicy
Aril flavor	sweet	sweet
Aril fragrance	Light fragrant	Absent
Edible percentage of fruit (%)	72.0 ± 3.2	70.9 ± 7.2
Total soluble solids content (°Brix)	16.7 ± 1.0	15.5 ±1.4
Quality	Good	Fair
Seed		
Weight per seed (g)	3.5 ± 0.3	2.2 ± 0.5

表 6.　「台農 7 號 (早大荔)」與「沙坑」荔枝物候期與植物性狀比較。(續)

Table 6. Phenology and morphological characteristics of litchi 'Tainung No. 7 (Early Big)' and 'Sah Keng'[z]. (continued)

Phenology and morphological characteristics	Tainung No. 7 (Early Big)	Sah Keng
Percentage of chicken tongue seed fruits (%)	20.7	20
Seed coat color	Brown	Brown
Shape of seed	Elliptic, chicken tongue	Elliptic, chicken tongue
Phenology		
Date of inflorescence emerging	Early January	Late January
Date of male flowering	Late February	Middle March
Date of female flowering	Early March	Late March
Date of functional male flowering	Middle March	Early April
Date of late flowering	Late March	Middle April
Date of fruit maturity	Late May	Middle June
Disease reaction		
Downy blight	Susceptibility	Susceptibility
Pest reaction		
Litchi fruit borer	Susceptibility	Susceptibility
Day of storage (5℃)	21	21

[z] The materials were investigated at Chiayi Agriculture Experimental Branch, Taiwan Agricultural Research Institute. (from 2007 to 2008).

[y] The words with underline mean the characteristic of 'Tainung No. 7 (Early Big)' is different from that of 'Sah Keng'.

重介於 25–35 g 間，以 28–32 g 居多；平均種子重介於 2–4 g 間，以 3 g 左右居多；焦核率不穩定，介於 5–50% 間，以 10–20% 居多，焦核的種子形態主要爲雞嘴形，大核的種子形態主要爲橢圓形 (圖 2A)。(6) 根據 2000–2009 年於嘉義、台南、高雄、屏東等地栽植「台農 7 號 (早大荔)」結果 (表 2–6) 顯示，除 2002 年受乾旱影響之外，「台農 7 號 (早大荔)」穩定呈現單穗平均著果量約爲 8–13 顆 (圖 2C、表 2–5)，產量穩定，無明顯隔年結果情形，與豐產品種「黑葉」、「沙坑」相當，優於「玉荷包」；平均單果重約爲 27.7–35.6 g 較「黑葉」、「沙坑」、「玉荷包」佳。(7) 果實採收期約爲 5 月上旬至 5 月下旬，一般較「黑葉」及「沙坑」早約 17–21 d 左右 (圖 2A、表 2)，亦較商業早熟品種「玉荷包」早約 10 d 以上 (表 3–5)。在我國商業栽培品種中，早熟品種以「玉荷包」爲代表，而豐產品種以「黑葉」及「沙坑」爲代表 (Yen *et al*. 1984; Hsu 2008; Chang & Teng 2012)。本品種兼具早熟、高產、大果等優質特性，以高壓法繁殖或藉「黑葉」、「玉荷包」爲砧木嫁接更新品種均能表現前述遺傳優點。

作物育種係冀望藉由改變作物遺傳組成，包含導入、組合或累加與優良性狀表現有關的遺傳因子，藉以產生使個體表現理想、與特定目標相符的新品種。屬於異質結合的果樹透過雜交方式育種，將有機會透過遺傳組成改變獲得某些性狀超越親本的後裔 (Shen 1984)。Li (2008) 以特早熟荔枝「991」爲母本、早熟荔枝「三月紅」爲父本雜交子代性狀分析結果顯示，後裔果實平均重量高過雙親平均，較接近父本「三月紅」，並有 40% 株系超越雙親；後裔平均種子重大於雙親平均、而可溶性固形物含量則接近雙親平均；此外調查觀察到 66.3% 後裔果肉質地傾向母本，風味、果肉率及果實成熟期亦多近於母本，而「台農 7 號 (早大荔)」果肉豐厚、質地細緻多汁、風味清甜等 (表 2、表 6)，果實特性即似承襲母本「沙坑」性狀。Fu *et al*. (2010) 調查以晚熟品種「馬貴荔」爲母本，早熟品種「焦核三月紅」爲父本雜交所得子代，果實發育期程部分反映出數量遺傳現象，約呈平均值與雙親中值接近之常態分佈，

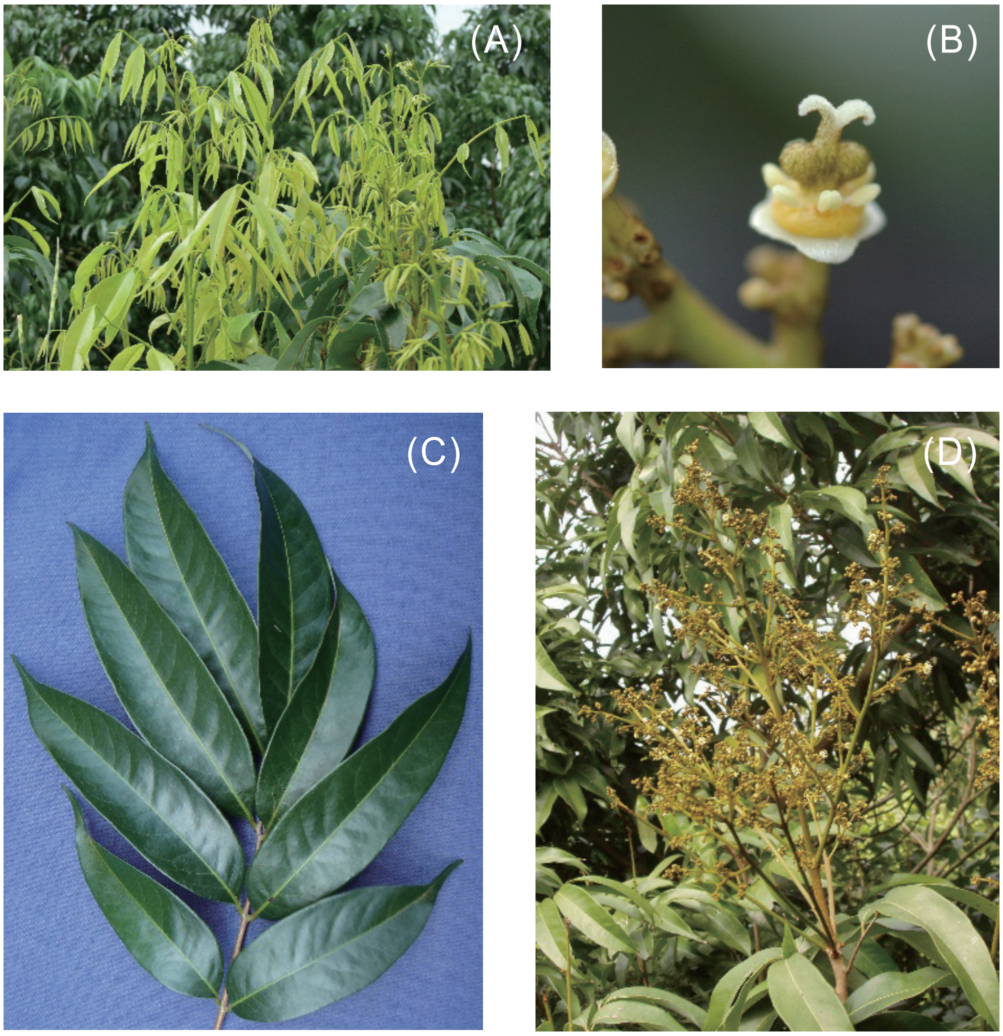

圖 1. 荔枝「台農 7 號 (早大荔)」形態外觀。(A) 新梢呈淺綠色；(B) 雌蕊柱頭微卷裂；(C) 小葉長橢圓形；(D) 長而疏之花序。

Fig. 1. The appearance of ‘Tainung No.7 (Early Big)’ litchi. (A) Color of young leaflets is light green; (B) The attitude of splitting stigma is arc-shaped; (C) The shape of leaflets is long-elliptic; and (D) The inflorescence is long and sparse.

且均有各有約 20% 超越雙親值之極端個體；然而各單株後裔果實成熟期落於 6 月 23 日至 7 月 21 日左右，介於「焦核三月紅」(6 月 9 日) 與「馬貴荔」(7 月 21 日) 間並較傾向母本，與 Li (2008) 描述相同，前敘結果暗示後裔族群產期具有母系遺傳影響。Chang *et al*. (2001) 分析其執行荔枝育種計畫檢視各品種荔枝子代遺傳性狀觀察到以中熟品種「沙坑」爲母本約有 8% 子代具極早熟性狀、36.8% 子代爲早熟，推測「沙坑」作爲母本具有自後裔族群更有效率地選育早生品系之潛力。雖然目前尚未清楚母本對後裔產期影響的遺傳及生理機制，但台灣已應用「沙坑」作爲選育優質早熟荔枝之用，除「台農 7 號 (早大荔)」外，Teng & Liu (2007) 育成之早熟荔枝品種「台農 2 號 (旺荔)」係以「沙坑」爲母本、「玉荷包」爲父本雜交而得。

產期過於集中及產量不穩定是世界荔枝產業的兩大問題 (Shen 1984; Yen *et al*. 1984;

圖 2. 荔枝「台農 7 號 (早大荔)」之果實特性。(A) 果實爲心形或橢圓形，焦核種子呈雞嘴形、大核種子呈橢圓形，果實成熟期較「黑葉」及「沙坑」早；(B) 果皮色澤紅；(C) 每穗結果數多。

Fig. 2. The fruit characteristics of 'Tainung No.7 (Early Big)'; (A) The fruit is elliptic or cordate in shape with normal or shriveled seeds. The harvest date is earlier than 'Hak Ip' and 'Sah Keng'; (B) Mature fruits have bright red peel; and (C) The cultivar shows good bearing ability.

Ghosh 2001; Chang *et al*. 2008; Hsu 2008; Wang *et al*. 2008; Yen 2008; Chang & Teng 2012)，因此選育不同產期且具穩定、豐產、優質品種一直是荔枝生產國的重點育種目標 (Shen 1984; Menzel & Simpson 1990; Chang *et al*. 2008; Li 2008; Fu *et al*. 2011)，早熟品種尤其如此 (Yen 2008)。在中國，3 月底時自泰國輸入之早熟荔枝價格高昂，至 4 月上、中旬上市荔枝果皮顏色黃綠、核大、味帶酸甜，價格仍較當年品質最優的「糯米糍」及「桂味」晚熟品種高 (Li 2008)。在澳大利亞，'Salathiel' 果品評價甚高 (Menzel & Simpson 1991; The Archive of the Rate Fruit Council of Australia 1993)，然其價格仍不及早熟品種「水東黑葉 (Souey Tung)」(Yen 2008)。相似的市場現象亦見於台灣，根據行政院農業委員會農產品交易行情站 (http://amis.afa.gov.tw/) 資料，2012 年 5 月中旬每公斤荔枝市場均價

為新台幣 86.3 元，較 5 月下旬高出 33.9 元；2013 年 5 月中旬每公斤荔枝市場均價為新台幣 92 元，較 5 月下旬高出 28.3 元，較 6 月上旬高出 55.1 元，顯示本地早熟品種同樣深具市場優勢。本品種在台灣南部地區可於 5 月下旬前採收，至屏東地區更可提前在 5 月上旬即可收穫 (表 2–5)，其產期較「玉荷包」早約 10 d，市場上荔枝供應量尚低，且本品種果實大、果皮鮮紅具良好賣相，品質風味近似於「沙坑」可為本地市場接受。此外，「玉荷包」生產過程需要疏花、除梢維持著果，以致栽培技術及成本偏高，而「台農 7 號 (早大荔)」生產過程無需這些成本投入，且單穗著果量可達「玉荷包」2 倍左右 (表 3–5)。如以「台農 1 號 (翠玉)」生產模式推估，本品種每公斤產量生產成本較「玉荷包」約低新台幣 16.7 元 (Chang *et al*. 2012)，因此「台農 7 號 (早大荔)」具備生產誘因與發展價值。在品種布局策略上若能於南部推廣品種更新，汰換部分「玉荷包」生產及收益不穩定園區使農戶轉作本品種，期可紓減並穩定 5 月下旬至 6 月上旬「玉荷包」產量輸出，進而提高「玉荷包」產業價值 (Chang & Teng 2012)，分散「玉荷包」近年面臨產銷不穩定風險。

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Breeding of Novel Litchi Cultivar 'Tainung No.7 (Early Big)'

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Abstract

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The novel litchi cultivar 'Tainung No.7 (Early Big)' was selected from progenies of the maternal parent 'Sah Keng' at Chiayi Agricultural Experiment Branch, Taiwan Agricultural Research Institute. The breeding program started in 1982 while the Plant Variety Right of this cultivar approved by the local authority in 2010. The cultivar was named for its 'early' harvesting season and 'big' fruit. In southern Taiwan, it can be harvested in early to late May, about 10 days prior to the commercial early-season cultivar 'Yu Her Pau' and 17 to 21 days prior to commercial mid-season cultivar 'Hak Ip' or 'Sah Keng'. Its production costs are lower than that of 'Yu Her Pau', yet it bears similar number of fruitlets on a panicle with the high yielding cultivars 'Sah Keng' and 'Hak Ip'. 'Tainung No.7 (Early Big)' litchi also has good fruiting ability and has no obvious alternate bearing, according to the results of varieties comparison and regional trials. The weight per fruit is about 25 to 35 g, with red peel, elliptic or cordate fruit shape, mild-sweet and juicy aril. With these special characteristics, it makes the cultivar valuable for commercial production and marketing. By taking advantages of early harvesting and the aforementioned characters, it will greatly eliminate problems of introducing this litchi variety to the market of Taiwan.

Key words: Taiwan, Litchi breeding, 'Yu Her Pau' litchi, 'Hak Ip' litchi, 'Sah Keng' litchi.

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未經冷馴化之草莓莖頂超低溫冷凍保存研究

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摘要

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草莓 (*Fragaria* × *ananassa* Duch.) 屬於薔薇科 (Rosaceae) 多年生高價值經濟作物，並且有超過 70 個以上的國家進行栽培與量產，因此進行種原的長期保存益顯重要。本試驗的主要目的，在於建立未經冷馴化草莓 (「桃園 1 號」) 最適宜的超低溫冷凍保存處理方法。培植體在尚未浸入液態氮前的預處理結果如下：(1) 莖頂培植體 (1–2 mm^3) 預培養於添加 0.3 M 蔗糖之 MS 基本鹽類培養基 14 d 後的平均存活率為 100%；(2) 將填充溶液 (LS) 中的蔗糖濃度自 0.6 M 提升至 1.6 M 並且滲透壓保護 90 min，莖頂的平均存活率仍可達到 100%；以及 (3) 使用植物玻璃質化溶液 2 (PVS2) 脫水 60 min 後之莖頂平均存活率達到 96.7% ± 4.7%，此百分比顯著高於 PVS2 脫水 180 min (60.0% ± 14.1%) 和 240 min (46.7% ± 17.0%) 的處理組。經 PVS2 脫水後，每 10 顆含莖頂的藻膠球及 0.3 mL 新鮮的 PVS2 被置入 1 個 2 mL 容量的抗凍管中，然後直接投進 -196℃的液態氮至少保存 1 h，經液態氮凍存後的抗凍管，在 38℃恆溫水槽中迅速回溫 60 s，此種含有莖頂的藻膠球繼代培養 14 d 後的再生率可達到 80%。本研究各項試驗結果，將有助於建立及簡化草莓超低溫冷凍保存的程序。

關鍵詞：草莓、超低溫冷凍保存、填充溶液、滲透壓保護、植物玻璃質化溶液 2。

前言

草莓 (*Fragaria* × *ananassa* Duch.) 爲薔薇科 (Rosaceae) 草莓屬 (*Fragaria*) 多年生草本作物，原產於歐洲及南美洲等地區。其果實由花托發育而成，外觀多呈心形或扇形，有淡紅、鮮紅及桃紅等色澤，味道酸甜可口，富含維生素 C、水楊酸、檸檬酸及具有美白效用的鞣花酸 (ellagic acid) 等成分，因一些商業品種的果實具有獨特香氣，故深受世界各國人們的喜愛。目前，市場上較常見到的栽培種草莓係由 *Fragaria chiloensis* L. P. Mill. 和 *Fragaria virginiana* Duch. 2 個原生種自然雜交育成，每年約有超過 70 個以上的國家進行量產栽培，且全世界的田間總種植面積已達到 50,600 ha (Sakila *et al*. 2007)。根據 2012 年行政院農業委員會農糧署統計指出，國內包含台北、新竹、苗栗、台中及南投等縣市的草莓總栽培面積合計約有 576.9 ha，其中苗栗縣即佔了 465.3 ha。若以單一鄉鎮進行比較時，又以大湖鄉的 374.3 ha 爲最大栽種區域，栽培的品種係以「豐香」爲主，估算大湖鄉的採收量可達 15,000 kg ha^{-1}。若以 1 kg 市價新台幣 500 元計算，則其產值高達每公頃 7,500,000 元。由此可知，草莓在我國可歸類爲高經濟價值作物，故研究無病毒健康種苗繁殖及種原保存技術也益顯重要。

近代由於自然環境遭到人爲的濫墾破壞，加上全球氣候持續暖化，年均溫逐年升高，致使區域原生物種面臨極嚴峻的生存考驗，惟有積極進行環境保護及作物遺傳資源保存與利用，方能永續生產安全的糧食。以作物種原保存而言，世界各作物種原中心採用的保存制

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度概可分為 3 種類型：(一) 原生地現地保存 (*in situ* conservation)；(二) 將種原移植至適當處所集中管理的離場保存 (*ex situ* conservation)；以及 (三) 利用組織培養等技術進行種原無性繁殖之離體保存 (*in vitro* conservation) (Engelmann 1991)。對於大多數田間作物而言，篩選優良種子並在低溫與低濕下貯藏是保存大量種原並使其能進行分贈或交換的最較佳方式，不耐低溫貯藏的植物種子則可藉由收集花藥或花粉進行保存 (Bajaj 1978)，或定期將營養繁殖的子代移植於田間進行種原更新。若以非種子型態保存且應用液態氮進行超低溫冷凍保存 (cryopreservation) 培植體的方法，則歸屬於前述第三種類型，國外學者曾撰文介紹草莓超低溫冷凍保存相關技術 (Reed & Hummer 1995)。植物超低溫冷凍保存技術多將培植體先經過預培養、低溫冷馴化 (cold hardening)、應用滲透壓保護 (osmoprotection) 填充溶液 (loading solution; LS) 以及浸漬於植物玻璃質化溶液 2 (plant vitrification solution 2; PVS2) 進行脫水 (dehydration) 等程序，再將莖頂、體胚或芽體置入 -196℃的液態氮中長期保存。在此極度低溫下，植物器官或組織的生理代謝已接近停止狀態，但仍舊保有生命的活力，待將其取出並迅速回溫及再生培養後，即可誘導發育成為完整的植株 (Engelmann 2004)。前述方法具有減少保存種原耗用的土地空間和人力成本的優點，也能避免外在環境如溫度、降雨、日照、病害或蟲害等因子的干擾 (Keller *et al*. 2006)。

參閱目前已發表的草莓種原超低溫冷凍保存研究論文，其幼嫩苗株在試驗過程，多先在 25℃、光照周期 16 h 的環境培養 14 d，再於溫度 5℃、光照周期 8 h 的環境下低溫冷馴化處理 20 d (Niino 2006)；或是先在室溫、光照周期 14 h 的環境預培養 25–30 d，再移至 10℃、光照周期 8 h 的環境下冷馴化處理 30 d，再執行後續的滲透壓保護及脫處理 (Hwang 2007)，亦即完成整個研究的期程需時較長。因此，本研究之主要目的，係有系統地探討未經冷馴化草莓 (「桃園 1 號」) 莖頂的超低溫冷凍保存技術，在幼嫩苗株未經低溫馴化培養且尚未置入液態氮的情形下，先運用含不同蔗糖濃度的培養基進行預培養，再依序使用含不同蔗糖濃度的 LS 和 PVS2 進行前處理，以檢測對於莖頂培植體存活率之影響。最終，則是將經過前處理的莖頂培植體置入液態氮中，且至少保存 1 h 後取出，再進行最佳回溫時間之探討。彙整本研究各項的試驗結果及累積相關實務經驗，以期有助於簡化草莓超低溫冷凍保存的程序，以及建立國家種原中心自有之作物超低溫冷凍保存技術。

材料與方法

供試材料來源

本試驗所使用的草莓「桃園 1 號」(*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') 種原係取自農業試驗所作物種原組。草莓新生芽體先以 75% 的乙醇溶液浸漬 30 s，再使用 0.5% 次氯酸鈉水溶液消毒處理 10 min，最後在無菌操作台內以無菌水清洗 3 次後切取莖頂部位，並接種培養於含有 MS (Murashige & Skoog 1962) 基本鹽類、0.2 mg L^{-1} 6-benzylaminopurine (BAP)、0.1 M 蔗糖及 0.8% 洋菜粉之培養基中 2 mo.，此後每隔 3–4 mo. 繼代培養 1 次。

不同蔗糖濃度預培養對莖頂存活率之影響

在無菌操作台內將草莓組織培養苗從試管中取出，並藉由解剖顯微鏡輔助切取 1–2 mm^3 莖頂作為供試培植體，培植體分別接種於添加不同蔗糖濃度 (0.1、0.2、0.3 及 0.4 M) 的 MS 固體培養基中，並置於恆溫 21℃、38–40 μmol m^{-2} s^{-1} 光合成光子流量密度 (photosynthetic photon flux density; PPFD) 及光週期 14 h 的培養室預培養 14 d 後，調查莖頂培植體之存活率。

LS 和 PVS2 前處理對莖頂培植體存活率之影響

包埋：選取預培養於 MS 固體培養基 (含 0.3 M 蔗糖) 中 14 d 的小苗株，藉由解剖顯微鏡輔助，切取莖頂作為供試培植體，在使用 LS 和 PVS2 浸漬之前，每個培植體皆先進行包埋處理。包埋溶液配方分成 A、B 兩種，A

溶液包含已去除 $CaCl_2$ 的 MS 基本鹽類、2% 藻膠與 0.4 M 蔗糖等成分；B 溶液則含有 MS 基本鹽類、0.4 M 蔗糖和 0.1 M $CaCl_2$ 等成分。包埋程序係以微量吸管吸取 A 溶液後，再以 1 個莖頂培植體定量使用 0.18 mL 的方式，將其一併滴入 B 溶液中進行滴定包埋，在 25℃下靜置 5 min 後，即可凝固形成直徑約 4 mm 且包埋單一莖頂培植體的藻膠球。

不同 LS 滲透壓處理對莖頂培植體存活率之影響：將包埋有單一培植體的藻膠球分別自 B 溶液中取出，並放入鋪有濾紙的玻璃培養皿吸除多餘的溶液，再將其置入 2 mL 容量之抗凍管中，每 1 支抗凍管置入 10 個藻膠球，且依不同處理試驗需求，分別在抗凍管中個別加入含不同蔗糖濃度的 LS 進行滲透壓保護 90 min，LS 配方含有 MS 基本鹽類、2 M 甘油及不同濃度 (0.6、0.8、1.0、1.2、1.4 和 1.6 M) 的蔗糖。各處理組在浸漬後，先以微量吸管將 LS 吸出，再依序使用含 1.0、0.4 和 0.2 M 蔗糖濃度的 MS 培養液各浸漬清洗 10 min，以逐步降低藻膠球中的蔗糖含量。最後，利用濾紙將藻膠球上殘留之溶液吸乾，置於 MS 固體培養基中培養 14 d，觀察及比較各處理組培植體的存活率。

不同 PVS2 脫水處理時間對莖頂培植體存活率之影響：取包埋單一莖頂培植體且經 LS (含 1.6 M 蔗糖) 滲壓保護處理 90 min 的藻膠球作爲供試材料，分別將其置入 2 mL 容量之抗凍管中，每 1 支抗凍管置入 10 個藻膠球，且在抗凍管中個別加入 PVS2 浸漬及脫水處理，PVS2 溶液主要含有 MS 基本鹽類、0.4 M 蔗糖、30% 甘油、15% 乙二醇 (ethylene glycol) 和 15% 二甲基亞碸 (dimethyl-sulfoxide; DMSO)，pH 值爲 5.8；進行浸漬脫水時間分爲 60、120、180 及 240 min，脫水處理完成後，先以微量吸管將 PVS2 吸出，再依序使用含 1.2、1.0、0.4 和 0.2 M 蔗糖濃度的 MS 培養液各浸漬清洗 10 min。最後，利用濾紙將藻膠球上殘留之溶液吸乾，置於 MS 固體培養基中培養 14 d，觀察及比較各處理組培植體的存活率。

抗凍管內不同 PVS2 體積與凍存後回溫時間對莖頂培植體再生率的影響

取包埋單一莖頂培植體且依序經 LS (含 1.6 M 蔗糖) 滲壓保護處理 90 min 和 PVS2 浸漬脫水 60 min 的藻膠球作爲供試材料，將其置入 2 mL 容量之抗凍管中，每 1 支抗凍管置入 10 個藻膠球，再分別於不同的抗凍管內加入不同體積 (0.3、0.5 及 1.0 mL) 的 PVS2 抗凍液。最後，直接浸入液態氮中超低溫冷凍保存 1 h，再將上述三種不同 PVS2 體積之處理組迅速置入 38℃恆溫水槽中，個別進行不同回溫時間 (60、90 及 120 s) 對於草莓 (「台農 1 號」) 莖頂培植體再生率的影響試驗。各處理組回溫完成後，先以微量吸管將 PVS2 吸出，再依序使用含 1.2、1.0、0.4 和 0.2 M 蔗糖濃度的 MS 培養液各浸漬清洗 10 min，最後，利用濾紙將藻膠球上殘留之溶液吸乾，置於含有 MS 基本鹽類、0.2 mg L^{-1} BA、0.1 M 蔗糖及 0.8% 洋菜粉之再生培養基中培養 14 d，調查和比較各處理組莖頂培植體的再生率。

試驗統計分析

以上試驗每一處理皆重複 3 次，每 1 重複使用 10 個培植體，獲得的數據資料計算其算術平均值及標準差 (standard error; SE)，並以 SAS 統計軟體進行變方分析 (analysis of variance; ANOVA)，在 5% 顯著性水準下以最小顯著差異性測驗 (least significant difference test; LSD test) 檢定各處理間差異的顯著性。

結果

不同蔗糖濃度預培養對莖頂存活率之影響

草莓組織培養苗從試管中取出並切取莖頂作爲供試材料，分別預培養於含 0.1、0.2、0.3 和 0.4 M 蔗糖濃度的 MS 固體培養基 14 d，經統計分析結果顯示，培養於前三項處理組的莖頂培植體存活率皆達到 100% (圖 1)，顯著高於含 0.4 M 蔗糖濃度之處理組 (86.7% ± 9.4%)。

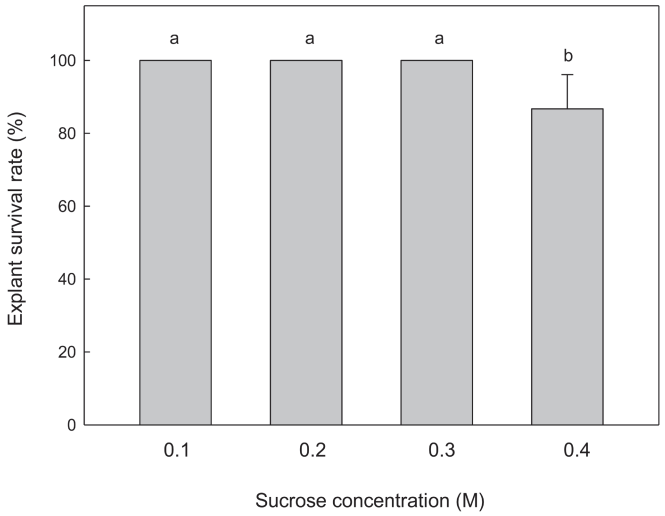

圖 1. 不同 MS 培養基 (蔗糖濃度：0.1、0.2、0.3 及 0.4 M) 預培養 14 d 之草莓 (「桃園1號」) 莖頂培植體存活率。

Fig. 1. The survival rates of strawberry (*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') shoot tip explants precultured on different MS media (sucrose concentrations: 0.1, 0.2, 0.3, and 0.4 M) for 14 d. Vertical bars indicate standard error (n = 3).

不同 LS 滲壓處理對莖頂培植體存活率之影響

將包埋有單一莖頂培植體的藻膠球分別置入 2 mL 容量之抗凍管，並在各抗凍管中個別加入含不同蔗糖濃度 (0.6、0.8、1.0、1.2、1.4 及 1.6 M) 的 LS 溶液進行滲透壓保護處理 90 min，再置於 MS 固體培養基培養 14 d。試驗結果顯示，莖頂培植體不論是使用含有 0.6 M 蔗糖濃度的處理組 (代號 LS 0.6 M) 或是添加量達到 1.6 M 的處理組 (代號 LS 1.6 M)，調查其試驗後之存活率皆為 100% (圖 2)。

PVS2 脫水處理對莖頂培植體存活率之影響

將包埋有單一莖頂培植體且經 LS (含 1.6 M 蔗糖) 滲壓保護處理 90 min 的藻膠球置入 2 mL 容量抗凍管中，再加入 PVS2 進行浸漬脫水 60 min 的處理組，其培養於 MS 固體培養基 14 d 後之存活率最佳為 96.7% ± 4.7% (圖 3)，高於浸漬脫水 120 min 者 (73.3% ± 4.7%)，也顯著優於浸漬脫水時間達 180 min (60.0% ± 14.1%) 及 240 min (46.7% ± 17.0%) 的處理組。

抗凍管內不同 PVS2 體積與凍存後回溫時間對莖頂培植體再生率的影響

將包埋有單一莖頂培植體且經 LS (含 1.6 M 蔗糖) 滲壓保護處理 90 min 和 PVS2 浸漬脫水 60 min 後的藻膠球置入 2 mL 容量之抗凍管中，以 -196℃ 液態氮進行凍存之前，於抗凍管內先加入 PVS2 抗凍液 0.3 mL 且凍存後迅速回溫 60 s (代號 RW60s) 的處理組，其培養 14 d 後之平均再生率最高達到 80% (表 1)，顯著高於加入 0.5 mL (63.3% ± 4.7%) 或 1.0 mL (60.0% ± 0.0%) PVS2 之處理組，且此種培植體經培養 6 mo. 後，已發育成為根系強健的苗株 (圖 4)；若比較回溫時間 90 s (代號 RW90s) 或 120 s (代號 RW120s) 的各個處理組，則抗凍管內不論是加入 0.3、0.5 或 1.0 mL 新鮮的 PVS2 抗凍液，其莖頂培植體平均再生率僅分別為 53.3–70.0% 及 46.7–60.0% (表 1)。

討論

自從 1976 年 Seibert 首度將康乃馨莖頂組織應用超低溫技術予以保存迄今，此一技術已被廣泛應用於更多的植物種類 (Bajaj 1991)。在日本學者編撰有關其國內植物細胞和器官超

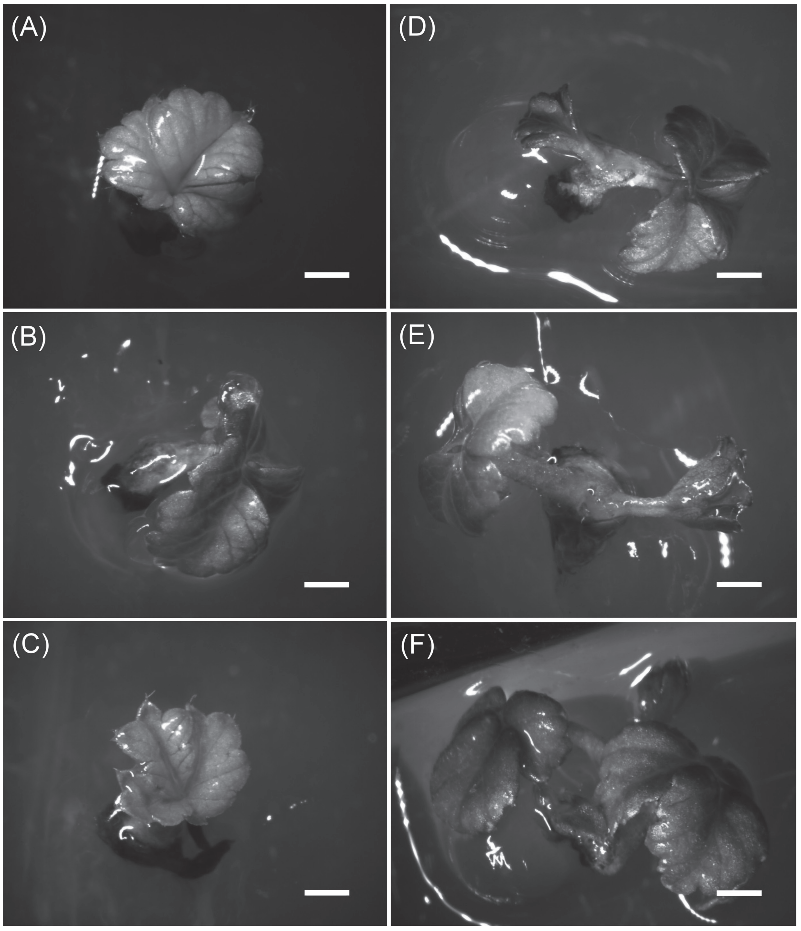

圖 2. 不同填充溶液 (LS) 浸漬 90 min 再培養 14 d 後之草莓 (「桃園 1 號」) 莖頂培植體。 (A) LS 0.6 M；(B) LS 0.8 M；(C) LS 1.0 M；(D) LS 1.2 M；(E) LS 1.4 M；(F) LS 1.6 M。 (比例尺 = 1 mm)

Fig. 2. The shoot tip explants of strawberry (*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') after immerged in different loading solutions (LS) for 90 min and then cultured for 14 d. (A) LS 0.6 M; (B) LS 0.8 M; (C) LS 1.0 M; (D) LS 1.2 M; (E) LS 1.4 M; (F) LS 1.6 M. (Scale bar = 1 mm)

低溫冷凍保存進展的研究專書中，也列舉了包含草莓、甘藷、龍膽、百合、星辰花、柿子、梨、櫻桃、柑桔和櫻花等多種草本及木本類植物 (Niino *et al*. 2006)。植物種原之莖頂、器官或組織運用超低溫冷凍技術進行保存所需的空間較之田間保存小，故為無性繁殖作物長期貯存以維持種原和基因性狀穩定的適當選擇。但在培植體玻璃質化且浸入液態氮前，必須先藉助較高濃度的含糖溶液、LS 和 PVS2 等預處理，以達到滲透壓保護和脫水的效果；另在解凍回溫過程中，也需儘量縮短時間並設法降低細胞間隙產生冰晶造成傷害，或是避免嚴重脫水導致原生質膜遭到破壞，以致於喪失正常的生理機能。上述各項處理程序，被認為是影響玻璃化冷凍保存技術成功與否的主要因子 (Thomashow 1999; Ashworth & Pearce 2002; Hirai & Sakai 2003)。

此外，利用適度的低溫環境進行苗株之冷馴化培養，則有助於提高超低溫冷凍保存後培植體的存活率與植株再生率 (Chang & Reed 2000)。Hwang (2007) 研究以玻璃化法超低溫冷凍保存草莓種原時，即先將瓶苗置於 10℃ 低溫冷馴化 30 d，再切取莖頂分生組織進行試驗，最終得到 85% 以上的培植體存活率。

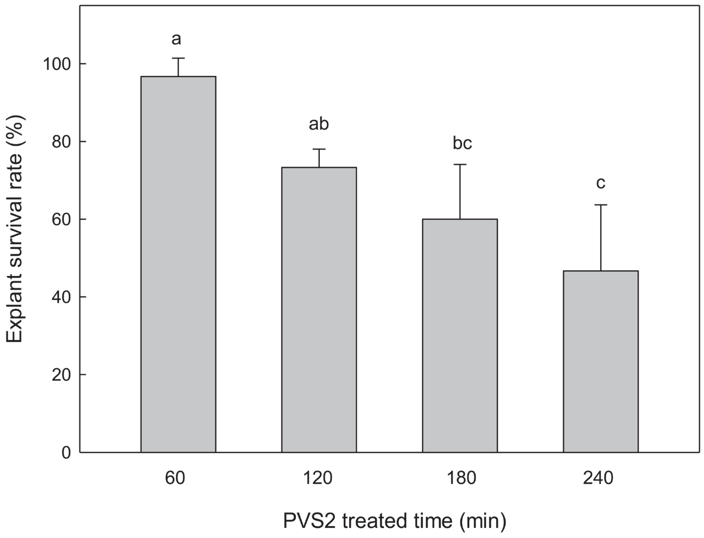

圖 3. 植物玻璃質化溶液 2 (PVS2) 處理不同時間 (60、120、180 及 240 min) 後的草莓 (「桃園 1 號」) 莖頂培植體存活率。

Fig. 3. The survival rates of strawberry (*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') shoot tip explants after treated with Plant Vitrification Solution 2 (PVS2) for different time period (60, 120, 180, and 240 min). Vertical bars indicate standard error (n = 3).

表 1. 凍存管中不同植物玻璃質化溶液 2 (PVS2) 體積與液態氮凍存 1 h 後之回溫時間對於草莓 (「桃園 1 號」) 莖頂培植體再生率的影響。

Table 1. Effects of different volumes of Plant Vitrification Solution 2 (PVS2) on cryotube and rewarming time on the regeneration rate of strawberry (*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') shoot tip explants after immerged into liquid nitrogen for 1 h[z].

PVS2 volume/	Shoot tip explants regeneration rate (%)		
Cryotube (mL)	RW60s[y]	RW90s	RW120s
0.3	80.0 ± 0.0 a[x]	70.0 ± 21.6 a	60.0 ± 14.1 a
0.5	63.3 ± 4.7 b	56.7 ± 4.7 a	56.7 ± 9.4 a
1.0	60.0 ± 0.0 b	53.3 ± 9.4 a	46.7 ± 12.5 a

[z] The shoot tip explants were precultured on MS medium for 14 d, and then pretreated with LS 1.6 M for 90 min and PVS2 for 60 min before immerged into LN (-196℃). MS medium: MS basal salts + 102.6 g L^{-1} sucrose + 0.8% Difco agar, pH = 5.8. LS 1.6 M: MS basal salts + 184.18 g L^{-1} glycerol + 547.2 g L^{-1} sucrose, pH = 5.8. PVS2: MS basal salts + 136.8 g L^{-1} sucrose + 30% glycerol + 15% ethylene glycol + 15% dimethyl-sufoxide, pH = 5.8.

[y] RW60s: cryotubes with shoot tip explants were rapidly rewarming in a water bath at 38℃ for 60 s.

[x] Means followed by the same letter in the same column are not significantly different at 5% level by Fisher's protected least significance difference (LSD) test (n = 3).

Hirai *et al*. (1998) 則是先將草莓苗株置於 23℃ 的環境培育 28 d，再移至 4℃ 環境冷馴化培養 7–14 d，最後切取 1 mm^3 的莖頂組織，預培養於含 1/2 MS 基本鹽類和 0.3 M 蔗糖的固體培養基 16 h 後，才開始作爲供試之材料。本試驗則是將未經冷馴化培養的草莓苗株自試管取出，在解剖顯微鏡輔助下，直接切取莖頂作爲供試材料，經預培養於含 0.3 M 蔗糖濃度的 MS 固體培養基 14 d 後的存活率達到 100% (圖 1)，顯著高於含 0.4 M 蔗糖濃度處理組之存活率 (86.7% ± 9.4%)。顯示草莓苗株在適應高張溶液培養時，培養基中添加的蔗糖濃度可適度提高到 0.3 M，此也與 Hirai *et al*. (1998) 以及 Niino *et al*. (2003) 所發表的處理程序相符合。

圖 4. 莖頂以液態氮超低溫冷凍保存 1 h，再回復生長及繼代培養 6 mo. 後的草莓 (「桃園 1 號」) 苗株。(比例尺 = 1 cm)

Fig. 4. The plantlet of strawberry (*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') after shoot tip cryopreserved in liquid nitrogen for 1 h and then recovered by growth and subculture for 6 mo. (Scale bar = 1 cm)

另在本項試驗過程中，同時觀察到莖頂培植體預培養於含 0.1 M 較低蔗糖濃度的 MS 固體培養基 7 d 後，培植體第 1 片新葉已完全展開且第 2 片葉也開始生長，至於其他處理組 (含蔗糖濃度 0.2、0.3 和 0.4 M) 之第 1 片新葉此時才開始生長，顯示含較高蔗糖濃度的培養基可能會延緩草莓莖頂的生長速率 (資料未列出)。

日本學者 Matsumoto *et al*. (1998) 研究指出，植物組織在 PVS2 脫水及浸入液態氮冷凍保存前，若先以 LS 浸漬處理，可使細胞質壁分離 (plasmlysis) 並避免冰晶形成破壞細胞膜結構。此外，含有高濃度蔗糖的 LS 也能滲透填充於細胞膜間隙及穩定組織結構，從而提高超低溫冷凍保存後之培植體存活率。Hiral & Sakai (2003) 也曾報導使用含不同蔗糖濃度 (0.6、0.8、1.0、1.2、1.4、1.6 及 1.8 M) 的 LS 進行甘藷藻膠球滲透壓保護處理 3 h，結果 LS 添加 1.6 M 蔗糖濃度的處理組，其萌生新芽的比率最高達到 80% 以上。Hiral & Sakai (1999) 在未經 4℃冷馴化培養的馬鈴薯腋芽滲透壓保護試驗中，使用含 0.6 M 蔗糖濃度的 LS 浸漬處理 90 min，調查其存活及萌芽比率也達到 70% 以上。本試驗則是將包埋有單一莖頂培植體的藻膠球置入抗凍管，並個別加入含不同蔗糖濃度的 LS 溶液進行滲透壓保護處理 90 min 後，即置於 MS 固體培養基培養 14 d，各處理組之莖頂培植體存活率皆為 100% 且發育良好 (圖 2)，顯示上述供試培植體對於 LS 中添加蔗糖的耐受濃度也可以高達 1.6 M。此一結果雖然與 Hwang (2007) 及 Niino (2006) 僅使用含 0.4 M 蔗糖濃度的 LS 溶液浸漬草莓培植體 20 min 或 60 min 之處理方法與時間不盡相同，不過，本試驗獲得的滲透壓保護條件，可作為後續 PVS2 脫水處理及提高培植體存活率之參考。

植物幼嫩分生組織在尚未直接置入 -196℃液態氮冷凍保存前，除上述先以 LS 滲透壓保護外，尚需經適度的脫水處理以提高未來使用 38–40℃溫水回溫後之存活率和植株再生率，一般常用的方法有藻膠包埋脫水法 (encapsulation-dehydration) (Scottez *et al*. 1992) 或是藻膠包埋玻璃質化法 (encapsulation-vitrification) (Wang *et al*. 2005)。以藻膠包埋玻璃質化法為例，在脫水及冷凍過程中，為保

護植物細胞活力並避免冰晶產生，學者會使用 PVS2 作為冷凍保護劑進行浸漬處理。由於其組成分中除了 1/2 MS 基本鹽類、0.4 M 蔗糖、30% (w/v) glycerol 和 15% (w/v) ethylene glycerol 外，還添加有 15% (w/v) DMSO，故為一種具有高滲透壓及輕微細胞毒性的溶液 (Sakai *et al*. 1990)。因此，依據冷馴化培養時間、植物的種類以及組織部位之不同，適當調整浸漬脫水處理的時間，方能增加培植體本身的抗凍能力且不致於過度傷害細胞活力 (Volk *et al*. 2006)。例如，將人參不定根先在 21℃暗培養 12 d 後，切取 3–4 mm 長度的培植體並以 LS 處理 15 min，再以 PVS2 脫水處理 15 min，可獲得 90% 以上的存活率；但 PVS2 脫水處理時間如超過 15 min，則不利於新根系之生成 (Oh *et al*. 2009)。百合莖頂分生組織經 0℃環境下冷馴化培養 30 d，再使用含有 0.3 M 蔗糖濃度的 LS 滲壓處理 20 min 後，不論是以 PVS2 在 0℃下浸漬 130 min 或是在 25℃下浸漬脫水 20 min，其新芽萌生比率皆可達到 90% (Matsumoto *et al*. 1995)。Hwang (2007) 在進行草莓玻璃質化試驗時，先以 10℃低溫冷馴化 30 d，續以含 0.4 M 蔗糖濃度之 LS 處理 20 min 後，再將莖頂培植體浸漬於 PVS2 脫水 150 min，結果仍有 97% 存活率。本試驗則是將未經冷馴化的草莓莖頂包埋形成藻膠球，再經 LS (含 1.6 M 蔗糖) 滲壓保護處理 90 min 後，置入 PVS2 中浸漬脫水 60 min，此種培植體經培養於 MS 固體培養基 14 d 後之存活率，最高達到 96.7% ± 4.7% (圖 3)。若浸漬脫水超過 120 min，則莖頂培植體之存活率急速降低，此與前述 Hwang (2007) 的試驗結果不盡相同，其原因可能是本試驗之供試材料未經低溫冷馴化培養且使用之 LS 蔗糖含量較高，當滲透壓保護處理時間較長時，部份培植體已顯現過度脫水的現象。

經查閱數篇有關草莓超低溫冷凍保存的國內、外研究論文，尚未有探討培植體以液態氮超低溫冷凍保存前，抗凍管內加入 PVS2 抗凍劑的體積及凍存後回溫時間對於培植體再生率的影響。例如，Hwang (2007) 在其研究論文中僅提到草莓頂芽在浸入液態氮前，於抗凍管內加入 0.5 mL 的新鮮 PVS2 抗凍劑，當凍存 1 wk 後取出，在 40℃恆溫水槽中迅速回溫 30 s。Niino *et al*. (2003) 的研究也僅敘述其在抗凍管內加入的 PVS2 抗凍劑體積為 0.5 mL，凍存 1 d 後在 35℃恆溫水槽中迅速回溫，但未提及回溫設定的時間。Hirai *et al*. (1998) 則是以草莓走莖莖頂作為試驗材料，其在抗凍管內加入的 PVS2 抗凍劑體積為 1 mL，凍存後在 38℃恆溫水槽中迅速回溫。本試驗的結果顯示，未經冷馴化的草莓莖頂包埋成藻膠球且經前處理後，置入 2 mL 容量之抗凍管中，在以 -196℃液態氮凍存前，只需於抗凍管內加入 0.3 mL 體積的 PVS2 抗凍劑且在凍存後回溫 60–90 s，其培養 14 d 後之平均再生率可達到 70–80% (表 1)，也優於其他用量的處理組。且此種培植體經繼代培養 6 mo. 後，可以發育成強健的苗株 (圖 4)。因此，本研究應可提供試驗過程中減少 PVS2 抗凍液用量之參考。

綜合上述各項試驗結果，可以繪製未經冷馴化之草莓莖頂超低溫冷凍保存之簡易操作流程 (圖 5)。亦即自田間採得草莓材料後，先建立無菌組織培養苗，在未經 4–10℃低溫冷馴化情形下，可直接將已去除葉片的短縮莖段接種於含 0.3 M 蔗糖濃度的 MS 固體培養基，並置於溫度 21℃、38–40 μmol m^{-2} s^{-1} PPFD 和光週期為 14 h 的環境預培養 14 d，再切取 1–2 mm^3 之莖頂分生組織作為超低溫冷凍保存的材料。經過包埋程序成為含有單一莖頂培植體的藻膠球，在尚未置入液態氮之前，先使用含 1.6 M 蔗糖濃度的 LS 滲透壓保護 90 min，再以 PVS2 浸漬脫水 60 min，最後才浸漬於 -196℃液態氮中長期冷凍保存。上述簡化操作流程的完成，不但省卻以低溫冷馴化所需的時間及節省空調電力等能源損耗，試驗過程也減少了 PVS2 抗凍液的用量，故本研究應有助於建構國家種原中心自有作物超低溫冷凍保存技術並簡化草莓超低溫冷凍保存的程序。

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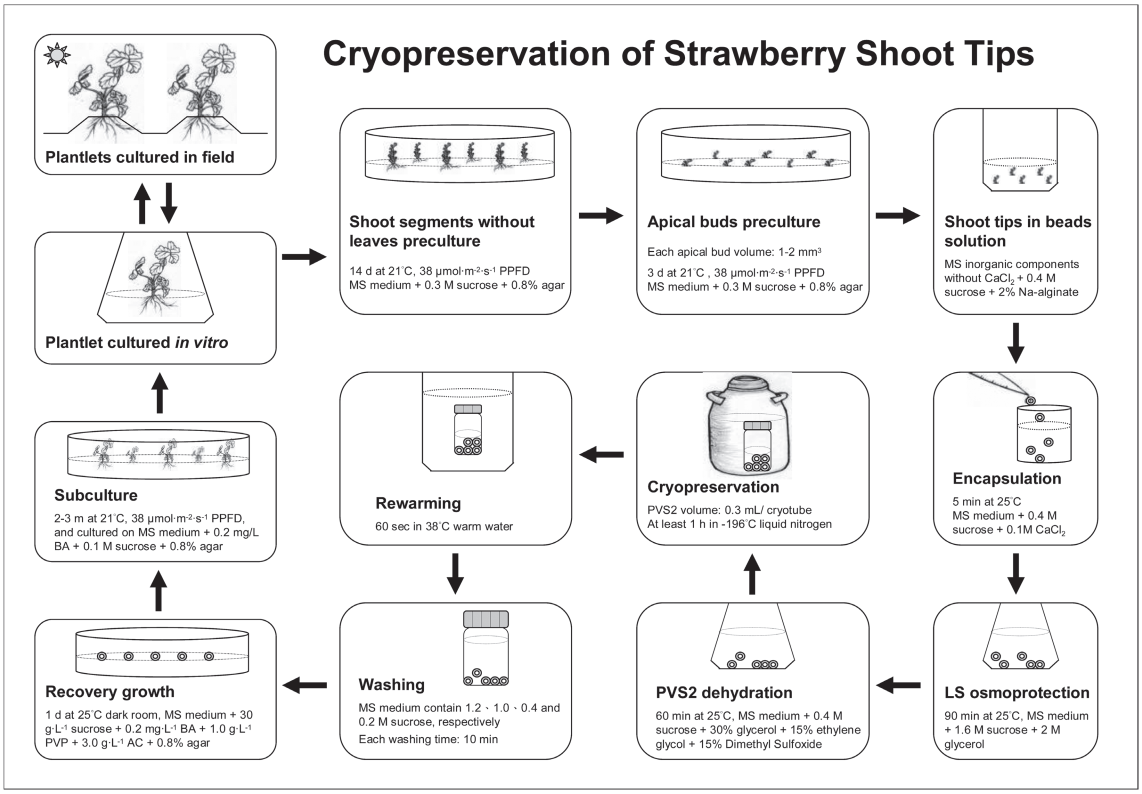

圖 5. 草莓 (「桃園 1 號」) 莖頂培植體超低溫冷凍保存之流程圖。

Fig. 5. Flow chart of the cryopreservation method of strawberry (*Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1') shoot tip explants.

Takao Niino 博士及島根大學 Toshikazu Matsumoto 博士指導，特此一併申謝。

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Study on the Cryopreservation of Non-cold Hardening *Fragaria* × *ananassa* Duch. Shoot Tips

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Abstract

Shiau, Y. J. and G. W. Chen. 2014. Study on the cryopreservation of non-cold hardening *Fragaria* × *ananassa* Duch. shoot tips. J. Taiwan Agric. Res. 63(1):57–67.

Strawberry (*Fragaria* × *ananassa* Duch.) is a high economic value perennial crop. It belongs to the Rosaceae family and is distributed in more than 70 countries. Therefore, the research on long-term storage of germplasm is important. The major objective of this study was to establish an optimum cryopreservation method of non-cold hardening *Fragaria* × *ananassa* Duch. cv. 'Taoyuan No.1'. The results obtained on pretreatment of explants prior to plunge into liquid nitrogen (LN) were as follows: (1) The survival rate of shoot tips (1–2 mm^3) was 100% when explants precultured on MS basal medium supplemented with 0.3 M sucrose for 14 d. (2) To increase sucrose levels from 0.6 M to 1.6 M in loading solution (LS) and then osmoprotected for 90 min, the survival rate of shoot tips remained 100%. (3) Survival rate of shoot tips achieved 96.7% ± 4.7% when treated with Plant Vitrification Solution 2 (PVS2) dehydration for 60 min. This percentage was significantly higher than treatments of PVS2 dehydration for 180 min (60.0% ± 14.1%) and 240 min (46.7% ± 17.0%). After PVS2 dehydration treatment, 10 shoot tip beads with 0.3 mL fresh PVS2 were transferred to a 2 mL cryotube and then plunged directly into LN for at least 1 h. After storage in LN, cryotubes were rapidly rewarmed in a water bath at 38℃ for 30 s. The final average regeneration rate of shoot tip beads (80%) was achieved after subcultured for 14 d. These research results appear promising for establishing and simplifying cryopreservation procedure of strawberry.

Key words: *Fragaria* × *ananassa* Duch., Cryopreservation, Loading solution, Osmoprotection, Plant Vitrification Solution 2.

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鳳梨嫡粉介殼蟲之分布與防治及其他害蟲調查

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摘要

黃守宏、林靜宜。2014。鳳梨嫡粉介殼蟲之分布與防治及其他害蟲調查。台灣農業研究 63(1):68–76。

本研究於 2010–2012 年在台灣 3 個主要栽培鮮食鳳梨地區調查害蟲之發生種類，結果顯示鳳梨嫡粉介殼蟲 [*Dysmicoccus brevipes* (Cockerell)] 為最主要發生之害蟲，另發現椰子盾介殼蟲 (*Diaspis boisduvalii* Signoret)、菝契黑圓盾介殼蟲 [*Melanaspis smilacis* (Comstock)] 及台灣黃毒蛾 [*Porthesia taiwana* (Shiraki)] 等 3 種新紀錄害蟲。分析鳳梨嫡粉介殼蟲族群於鳳梨園中呈現聚集型分布，發現於鳳梨果實形成後，聚集部位以果實基部為主，且與果實可溶性固形物含量呈正相關 (r = 0.62, P < 0.0001)。檢測 50% 撲滅松乳劑、50% 芬殺松乳劑及 40.8% 陶斯松乳劑等早期推薦之防治藥劑及 2% 農皂、90% 葵無露、60% 大豆油乳化劑及 99% 窄域油等 4 種油類資材，對鳳梨嫡粉介殼蟲之防治效果，顯示經兩次施藥後至第 21 d 調查，3 種原推薦藥劑均仍有良好之防治成效，惟 4 種油類資材之防治效果則與無施藥處理間差異不顯著。

關鍵詞：鳳梨、鳳梨嫡粉介殼蟲、分布、防治。

前言

台灣早期 (1985年以前) 種植之鳳梨品種，以適於加工製罐之「開英種」爲主，所生產之鳳梨主要作爲外銷爲用途。在 1970 年代，台灣之鳳梨製罐外銷量曾達 410 萬箱，居世界第一位。其後，隨著經濟起飛、工商業快速發展及農村勞力缺乏等因素，1980 年代開始台灣的鳳梨產業由「加工外銷爲主、內銷爲副」逐漸轉變爲「鮮食內銷爲主、外銷爲副」，栽培品種也轉變成爲以適合鮮食用品種爲主 (Chang & Kuan 2001)。目前鮮食用栽培品種以「台農 17 號」爲主，其次爲「台農 20 號」。惟鳳梨害蟲之相關研究仍爲 1970 年代以前，且內容主要針對嚴重危害鳳梨之萎凋病及其媒介昆蟲 (鳳梨嫡粉介殼蟲) 防治試驗 (Sun 1957; Lee 1964, 1966; Lee & Chien 1967)。另外，因鳳梨嫡粉介殼蟲與螞蟻之共生關係，因而防治介殼蟲時，需一併防治共棲之螞蟻，以提高防治成效 (Sun 1957)。

然而，蟲害之發生隨作物品種及栽培環境等因素而改變，目前台灣鳳梨栽培以鮮食品種爲主，加上台灣鳳梨拓展外銷逐年成長，國人對食品安全觀念提升，是故如何生產安全農產品爲此產業重大課題。本研究係調查台灣鳳梨蟲害的發生及種類，建立害蟲名錄及發生生態等基本資料，提供未來研究參考，並探討早期推薦藥劑及目前可用防治資材之防治成效，提供生產者有效防治方法及建立鳳梨安全生產體系，使能生產安全之果品供消費者食用。

材料與方法

鳳梨害蟲發生種類及族群消長調查

自 2010 年 1 月至 2012 年 12 月，分別於嘉義縣、高雄市及屏東縣等主要鳳梨生產地區，各設置 2、1 及 1 塊調查園，每塊調查園

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面積分別爲 0.4、0.3、0.8 及 0.6 ha，每 0.1 ha 種植 3,500–4,000 株左右。調查品種以目前鮮食之鳳梨「台農 17 號」或「台農 20 號」爲主，每隔兩週於每調查園逢機取樣調查 80 株以上，以目視法連續調查 3 年，調查鳳梨不同生長時期及其果實上害蟲發生種類及族群消長，以了解目前主要害蟲發生種類及數量變化。

鳳梨嫡粉介殼蟲在果園上之空間分布

另於高雄市大樹區之有機栽培鳳梨「台農 17 號」果園 (田面積約 0.8 ha)，進行鳳梨嫡粉介殼蟲之空間分布調查，期間介於 2012 年 3 月至 6 月，每隔兩週逢機取樣調查 100 棵植株。亦以目視調查並記錄每棵植株上鳳梨嫡粉介殼蟲數量，直至鳳梨採收爲止，共計調查 10 次。空間分布之分析方法係藉由平均擁擠度 (Lloyd's mean crowding; m*) (Lloyd 1967) 及區塊指數 (index of patchiness) 表示，前者爲平均值加上取樣單位的變方 (S^2) 及其平均數 (m) 的比值 ($m^* = m + S^2/m$)，後者爲平均擁擠度之數值與平均值之比值 (m*/m)，此等數值 < 1、= 1 及 > 1 分別表示均勻、逢機及聚集型分布。最後再利用 Iwao (1968) 發展平均擁擠度與樣品均方間 (m*/m) 呈現直線關係，而將 Lloyd's mean crowding (1967) 對該族群之平均數作直線回歸，以其斜率值 (β) 作爲空間分布判別指標。β 值 < 1、= 1 及 > 1 分別表示均勻、逢機及聚集型分布。

鳳梨嫡粉介殼蟲在果實上之分布與可溶性固形物含量之關係

試驗田位於嘉義縣民雄鄉，面積約 0.4 ha，所栽植之鳳梨品種爲「台農 17 號」，調查期間在 2012 年 7 月至 8 月，調查取樣以 5–7 分熟之果實爲主，共計取樣 50 顆果實。將果實區分成上 (端部)、中 (中部)、下 (基部) 三等分，調查鳳梨嫡粉介殼蟲於各部位之發生數量。並將果實切開，用刀子切取上述部位之果肉，並將果肉擠壓出汁液，滴於手持式屈折度計 (ATAGO N-1, Japan) 檢測鏡面上，調查各部位之可溶性固形物含量變化。並進行相關性 (Pearson correlation coefficient) 分析，瞭解鳳梨嫡粉介殼蟲在不同果實部位上之分布與可溶性固形物含量間之關係。

藥劑防治鳳梨嫡粉介殼蟲之效果評估

針對部分已完成殘留量衰退檢測試驗，且已訂定安全採收期之推薦防治鳳梨嫡粉介殼蟲藥劑：50% 撲滅松 (Fenitrothion) 乳劑 (利台化學工業股份有限公司)、50% 芬殺松 (Fenthion) 乳劑 (瑞芳化工廠股份有限公司) 及 40.8% 陶斯松 (Chlorpyrifos) 乳劑 (瑞芳化工廠股份有限公司)，再重新進行田間防治藥效之測試。試驗田位於嘉義縣民雄鄉，面積約 0.3 ha，每 0.1 ha 約種植 4,200 株，所栽植之鳳梨品種爲「台農 17 號」，調查期間在 2011 年 8 月至 9 月。依照《植物保護手冊》推薦用量及方法，配製檢測藥劑並採用其稀釋倍數及每公頃施用量，期將結果提供農民實際進行防治之參考。

另外，選用非化學合成 (油類) 防治資材：50% 農皂 (coconut oil) (東精生物科技有限公司)、90% 葵無露 (sunflower oil) (振詠興業有限公司)、60% 大豆油乳化劑 (soybean oil) (農委會農業試驗所應動組李啓陽博士提供) 及 99% 窄域油 (mineral oil) (玉田地公司)，進行鳳梨果實採收前之鳳梨嫡粉介殼蟲防治試驗。試驗田位於高雄市大樹區，面積約 0.5 ha，每 0.1 ha 約種植 4,500 株，所栽植之鳳梨品種爲「台農 17 號」，調查期間在 2012 年 5 月至 6 月。期將所得結果提供未來應用於有機栽培、一般慣行栽培或外銷供果園使用，於鳳梨採收前進行鳳梨嫡粉介殼蟲處理，以達到鳳梨果品上無害蟲及藥劑殘留之安全生產目的。

以上之藥劑試驗採逢機完全區集設計，每處理小區爲鳳梨 10 株，重複 4 次。施藥次數爲鳳梨發生粉介殼蟲時噴藥 1 次，隔 10 d 再噴藥 1 次。分別於施藥前調查 2 次，及第 2 次施藥後 7、14 及 21 d 各調查 1 次，以目視調查記錄每植株上粉介殼蟲蟲數。資料分析前先將調查蟲數經 $(X + 0.5)^{1/2}$ 轉換後，再以最小顯著差異法 (Fisher's least significant difference; LSD) 分析法比較各處理間蟲數之差異。

結果

鳳梨害蟲發生種類及族群消長調查

早期所記錄發生之鳳梨害蟲種類計有 15 種 (包含蟎類 1 種) (Tsai 1965)，本研究近 3 年來調查鮮食鳳梨上害蟲發生種類之結果增加了 3 種新紀錄種，分別為椰子盾介殼蟲 (*Diaspis boisduvalii* Signoret)、菝契黑圓盾介殼蟲 [*Melanaspis smilacis* (Comstock)] 及台灣黃毒蛾 [*Porthesia taiwana* (Shiraki)]，害蟲名錄整理如表 1。目前調查鮮食鳳梨最常發生之害蟲種類以鳳梨嫡粉介殼蟲為主，其次鳳梨盾介殼蟲、絲粉介殼蟲及菝契黑圓盾介殼蟲等。

由圖 1 顯示於 2010 年 3 月所新植的鳳梨種苗上，蟲害發生率達 31.3%，以鳳梨盾介殼蟲之密度最高；在植株催花後，果實抽出、成熟期間 (11 月以後)，蟲害發生率上升達 53.3%，以鳳梨嫡粉介殼蟲發生較多；果實採收後 (7 月以後)，鳳梨裔芽及吸芽生長期間，蟲害發生有上升之趨勢，其中亦包含絲粉介殼蟲、鳳梨盾介殼蟲及菝契黑圓盾介殼蟲等。

鳳梨嫡粉介殼蟲在果園上之空間分布

分析高雄市大樹區有機栽培鳳梨園之鳳梨嫡粉介殼蟲族群 (包含成蟲或若蟲) 的空間分布，取樣單位的變方及其平均數的比值 ($S^2 m^{-1}$)、平均擁擠度 (m*) 及區塊指數 (m*/m) 之結果 (圖 2)，分別介於 9.12–25.22、15.12–57.36 及 1.53–2.77 之間，顯示族群於園區中均呈現聚集型分布。進一步利用 Iwao’s m* − m regression 分析此蟲之空間分布型式，其斜率值 (β) 為 1.437，此數值經由 student *t*-test (α = 0.05) 檢定結果與 β = 1 呈顯著差異，更證實其族群為聚集型分布。Hughes & Samita (1998) 利用 LNB (logistic-normal-binomial) 方法分析，亦顯示鳳梨嫡粉介殼蟲於果園中呈現相同的聚集型分布型式。

鳳梨嫡粉介殼蟲在果實上之分布與可溶性固形物含量之關係

初步調查鳳梨嫡粉介殼蟲在 5–7 分熟之「台農 17 號」果實上 (端部)、中 (中部)、下

表 1. 台灣曾經記錄之鳳梨害蟲種類。

Table 1. The list of insect and mite pests recorded on pineapple in Taiwan.

Order	Scientific name	Common name	Chinese name
Orthoptera	*Acheta bimaculata* (De Geer)	Two-spotted cricket	黑蟋蟀
	Atractomorpha sinensis Bolivar	Pinkwinged grasshopper	紅后負蝗
	Oxya velox Fabricius	Short-horned grasshopper	長翅稻蝗
	Teleogryllus mitratus (Burmeister)		白緣眉紋蟋蟀
Isoptera	*Odontotermes formosanus* (Shiraki)	Black-winged subterranean termite	黑翅土白蟻
Hemiptera	*Diaspis boisduvalii* Signoret[z]	Boisduval scale	椰子盾介殼蟲
	Diaspis bromeliae (Kerner)	Pineapple scale	鳳梨盾介殼蟲
	Dysmicoccus brevipes (Cockerell)	Pink pineapple mealybug	鳳梨嫡粉介殼蟲
	Ferrisia virgata (Cockerell)	Striped mealybug	絲粉介殼蟲
	Melanaspis smilacis (Comstock)[z]	Smilax scale	菝契黑圓盾介殼蟲
	Podoparalecanium machili (Takahashi)		樟南足扇介殼蟲
	Pseudococcus citri (Risso)	Citrus mealybug	柑桔粉介殼蟲
	Pseudococcus longispinus (Targioni-Tozzetti)	Long-tailed mealybug	長尾粉介殼蟲
Coleoptera	*Anomala expansa* (Bates)	Cupreous beetle	台灣青銅金龜
Lepidoptera	*Agrotis ipsilon* (Hufnagel)	Black cutworm, Greasy cutworm	球菜夜蛾
	Porthesia taiwana (Shiraki)[z]	Taiwan yellow tussock moth	台灣黃毒蛾
	Spodoptera litura Fabricius	Tobacco cutworm, Cotton worm	斜紋夜蛾
Mite	*Dolichotetranychus floridanus* (Banks)	Pineapple false spider mite	鳳梨偽葉蟎

[z] new pests recorded in this study.

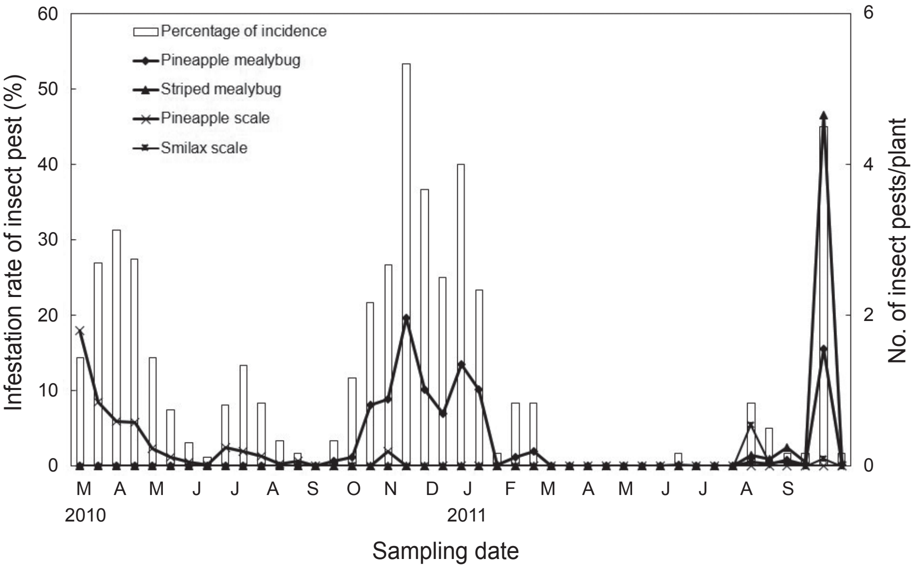

圖 1. 嘉義地區「台農 20 號」鳳梨田間主要蟲害發生消長及發生率之調查。

Fig. 1. The seasonal occurrence of major species of insect pests and infestation rate (%) on pineapple 'TNG20' in Chiayi, Taiwan.

(基部) 發生率，依果實成熟度及棲息蟲數之不同而略有不同，調查結果顯示上述三部位發生蟲率分別爲 0–10.00%、7.14–36.36% 及 63.64–92.86% (圖 3)，顯示此蟲聚集分布於果實基部爲主。果實各部位可溶性固形物含量檢測結果，依果實不同而略有差異，但同一果實中，仍以基部之可溶性固形物含量最高，端部則反之。在上述部位可溶性固形物含量檢測結果，分別爲 10.5–16.0、17.0–13.0 及 17.5–14.0 °Brix。經分析害蟲發生率與可溶性固形物含量間有正相關性，相關係數爲 0.62 (P < 0.0001) (圖 3)。

藥劑防治鳳梨嫡粉介殼蟲之效果評估

針對三種推薦防治鳳梨嫡粉介殼蟲藥劑 (50% 撲滅松乳劑、50% 芬殺松乳劑及 40.8% 陶斯松乳劑)，經重新進行鳳梨嫡粉介殼蟲防治效果檢測，資料以 LSD 分析法比較蟲數差異之結果如表 2。結果顯示，尚未施用藥劑前，處理區與對照區間之每株平均蟲數介於 22.94–57.13 隻之間，且無顯著差異。施用一次藥劑後，各藥劑處理區每株平均蟲數降至 0.31–1.56 隻，且與對照區 (平均 22.38 隻) 具有明顯差異存在。經兩次施藥後，三種藥劑至第 21 天之防治結果，每株害蟲平均密度介於 0.25–0.31 隻，與對照組 (平均 23.13 隻) 間呈顯著性差異，顯示具有良好之防治成效。

選用非化學合成防治資材包括農皂、葵無露、大豆油乳化劑及窄域油等，進行鳳梨果實之鳳梨嫡粉介殼蟲防治試驗結果如表 3。結果顯示，尚未施用藥劑前及第 1 次施藥後，處理區與對照區間之每株平均蟲數介於 24.44–37.19 與 27.75–39.40 隻之間，且無顯著差異。其中，60% 大豆油乳化劑稀釋 20 倍於第 2 次施用後 7 d，每顆蟲數雖仍達 14.88 隻，惟與對照組相較具有明顯之抑制效果，其餘防治資材則無顯著之成效。但在經第 2 次施藥後 14 d 及 21 d 之調查結果，上述各種有機防治資材處理區之發生蟲數皆與對照區差異不顯著。

討論

雖然台灣鳳梨栽培品種已有改變，害蟲發生種類卻仍以鳳梨嫡粉介殼蟲爲主，本研究調查發現了 3 種新紀錄害蟲，其發生與危害狀況有待持續監測。目前需要特別注意的問題，依然在於粉介殼蟲與所媒介萎凋病間之發生與

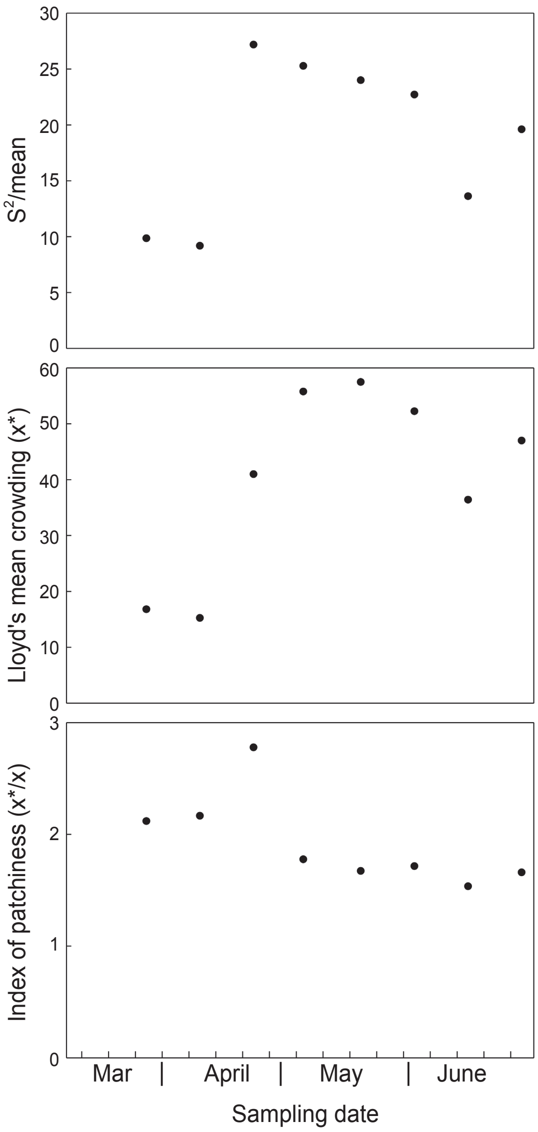

圖 2. 高雄市大樹區鳳梨園嫡粉介殼蟲的空間分散指數隨時間之變動情形。

Fig. 2. Fluctuations of dispersion indices of pink pineapple mealybug in pineapple field at Dashu District of Kaohsiung City in 2011.

防治問題 (Sether *et al*. 1998; Su 2001; Huang *et al*. 2002; Adebayo & Victor 2006)。台灣近年鳳梨栽培以鮮食鳳梨品種爲選育目標，育出新品種之果實可溶性固形物含量明顯比以前提高甚多，最高可達 18.4°Brix (Chang & Kuan 2001)。本研究調查鳳梨期間，在生育後期往往發現許多鱗翅目蛾類幼蟲取食食痕，但卻遍尋不著蟲體，初步研判爲夜蛾科之幼蟲爲害所致。另外，也常發現可溶性固形物含量高之果實遭遇嚴重鼠害問題，均爲未來鳳梨有害生物管理另需注意方向。

鳳梨於採收後，一般農民留取鳳梨母株進行裔芽及吸芽之繁殖，在此時期也多半採取粗放管理方式，容易滋生蟲害。爲避免所繁殖種苗 (裔芽及吸芽) 帶有蟲源 (圖 1)，移入至新植園區成爲感染源，蟲害防治工作仍不能荒廢，以避免後續管理上之困擾 (Su 2001; Williamson *et al*. 2008)。早期鳳梨粉介殼蟲防治工作，係將鳳梨種苗於種植前先進行浸藥處理，粉介殼蟲及其所媒介萎凋病的防治因而收到良好成效 (Lee 1966; Lee & Chien 1967)。惟目前因人力成本增加，此方法農民已經甚少採用，大多改以種苗種植後 1–2 wk 內，再灌注殺蟲劑及殺菌劑，以防除種苗上之病蟲害。但是，本文作者仍建議可延續種苗浸藥處理，以節省施藥量及達到較佳保護效果。

多數介殼蟲之空間分布型式屬於聚集型 (Nestel *et al*. 1995; Martínez-Ferrer *et al*. 2006; Beltrá *et al*. 2013)。經調查結果鳳梨嫡粉介殼蟲於鳳梨園中亦呈現相同的聚集型分布，針對此聚集型分布之害蟲管理，意味著最初感染源之控制爲重要管理關鍵。國內外許多報告指出，加強鳳梨園外圍區域，施藥防治粉介殼蟲所共生之螞蟻，可達到減少施藥量及良好防治成效之經濟目的 (Su *et al*. 1980; Reimer & Beardsley 1990; Su 2001)。根據此試驗之調查結果 (圖 1)，健康無帶蟲之種苗或種苗藥劑處理，亦爲蟲害管理之重點 (Lee & Chien 1967)。

鳳梨於催花後，果實逐漸形成期間，植株養分逐漸蓄積於果實上，也相對誘引害蟲聚集取食，其中以鳳梨嫡粉介殼蟲爲最主要發生害蟲種類 (圖 1)。經分析此蟲於果實上各部位呈聚集分布，而此分布與果實可溶性固形物含量間之相關性呈正相關 (r = 0.62, P < 0.0001) (圖 3)，惟可溶性固形物含量與此蟲生長發育間之關係，有待進一步探討。往昔研究曾指出鳳梨底部較陰涼、遮蔽性高，有利於此蟲之棲

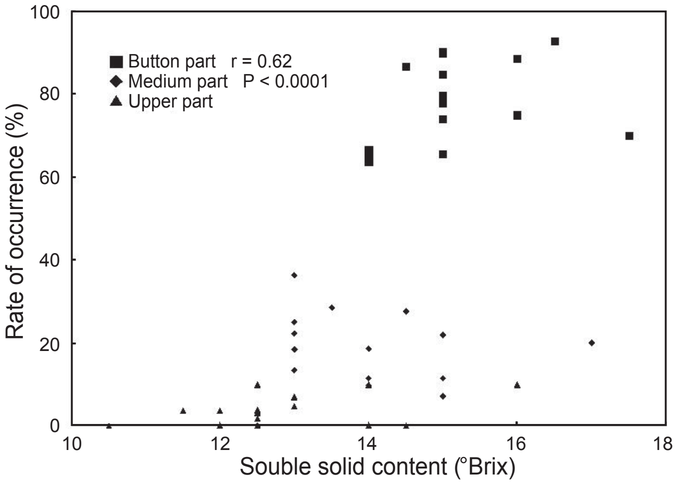

圖 3. 鳳梨「台農 17 號」果實不同部位之可溶性固形物含量與嫡粉介殼蟲發生率之關係。

Fig. 3. The relationships between rates of occurrence of pink pineapple mealybug and soluble solid contents in different parts of pineapple fruit.

表 2. 三種早期推薦藥劑對鳳梨嫡粉介殼蟲之防治效果。

Table 2. The efficacy of three pesticides recommended in the earlier time for the control of pink pineapple mealybug on pineapple.

	No. of pineapple mealybug pl^{-1}				
	Days after treatment				
Treatment	BI[z]	BII	7	14	21
50% Fenitrothion EC 2500×	57.13 a[y]	1.56 a	0.25a	0.31 a	0.31 a
50% Fenthion EC 1000×	32.88 a	0.69 a	0.25 a	0.25 a	0.25 a
40.8% Chlorpyrifos EC 2000×	24.44 a	0.31 a	0.25 a	0.25 a	0.31 a
CK	22.94 a	22.38 b	20.81 b	23.81 b	23.13 b

[z] BI: investigation before the first application of insecticide; BII: investigation before the second application of insecticide.
[y] Data was transferred by the formula $(x + 0.5)^{1/2}$ before analysis, and means followed by the same letter in a column do not statistically different by the least significant difference (LSD) test at the 5% level.

表 3. 四種非化學合成 (油類) 防治資材對鳳梨嫡粉介殼蟲之防治效果。

Table 3. Evaluation of the efficacy of four non-synthetic chemicals for the control of pink pineapple mealybug on pineapple.

	No. of pineapple mealybug pl^{-1}				
	Days after treatment				
Treatment	BI[z]	BII	7	14	21
2% Coconut oil 50×	37.19 a[y]	32.31 a	23.56 a	21.81 a	26.94 a
90% Sunflower oil 200×	33.13 a	27.88 a	25.13 a	24.06 a	28.44 a
60% Soybean oil 20×	24.44 a	39.40 a	14.88 b	17.25 a	18.25 a
60% Soybean oil 40×	35.31 a	31.75 a	34.75 a	24.56 a	29.06 a
99% Mineral oil 500×	35.88 a	30.44 a	25.50 a	19.36 a	19.56 a
CK	29.25 a	27.75 a	24.50 a	29.13 a	40.69 a

[z] BI: investigation before the first application of insecticide; BII: investigation before the second application of insecticide.
[y] Data was transferred by the formula $(x + 0.5)^{1/2}$ before analysis, and means followed by the same letter in a column do not statistically different by the lease significant difference (LSD) test at the 5% level.

息 (Lee & Chien 1967)，而本研究分析認為可溶性固形物含量為另一個誘引因素。鳳梨嫡粉介殼蟲通常由果梗往果實基部集中分布，其後隨其族群增長及果實逐漸成熟，其族群再逐漸往果實中部及冠部擴散。此結果顯示進行鳳梨嫡粉介殼蟲防治時，應把握在其族群發育初期，著重於果實基部之藥液噴灌，才能達到經濟有效防治之成效 (Lee & Chien 1967)。

藥劑防治法具有便宜、效果迅速及使用方便等特性，也為農民進行鳳梨粉介殼蟲管理之重要方法之一。但如何安全使用藥劑以符合台灣或外銷進口國安全殘留量之標準，乃鳳梨安全生產之重要課題 (Willamson *et al*. 2008)。本研究重新檢測於早期 (1970 年代) 推薦防治鳳梨嫡粉介殼蟲之 50% 撲滅松乳劑、50% 芬殺松乳劑及 40.8% 陶斯松乳劑等 3 藥劑，證實這些藥劑仍具有良好的防治效果，且經由殘留量衰退檢測試驗，已完成訂定符合台灣安全採收期 (3 藥劑均為 9 d)，對於農民藥劑防治使用上，提供更完整及安全之採收參考 (Wang *et al*. 2012)。

本研究另外測試窄域油 (礦物油)、大豆油乳化劑 (大豆油)、農皂 (椰子油) 及葵無露 (葵花油) 等非化學合成 (油類) 防治資材，對粉介殼蟲之防治效果。此等資材對害蟲防治機制均為堵塞氣孔，造成蟲體窒息死亡 (Hewllet 1975; Schoonhoven 1978)，並已推薦在多種害蟲防治上 (Butler *et al*. 1991; Koul *et al*. 2008; Yu 2009)。惟在本研究使用於防治鳳梨嫡粉介殼蟲，並未見明顯之效果 (表 3)。此外，部分油類防治資材在高溫日照下，易引發藥害之產生。在本試驗期間所採用之油類防治資材，雖無明顯藥害發生之現象，但在大豆油乳化劑之處理區，出現鳳梨尚未成熟的情況下，整顆果皮顏色變黃造成之傷害。為因應鳳梨果實上鳳梨嫡粉介殼蟲長期帶來之危害，對於其他種類有機防治資材之開發、選用及檢測，應為未來研究方向，以期達到有效防治此蟲及無藥劑殘留之安全採收目標。

誌謝

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Distribution and Control of Pink Pineapple Mealybug and Survey of Insect Pests on Pineapple

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Abstract

Huang, S. H. and C. Y. Lin. 2014. Distribution and control of pink pineapple mealybug and survey of insect pests on pineapple. J. Taiwan Agric. Res. 63(1):68–76.

Surveys of insect pests on pineapple were carried out from 2010 to 2012 in three major pineapple cultivation areas in Taiwan. The results showed that pink pineapple mealybug [*Dysmicoccus brevipes* (Cockerell)] occurred more frequently than the other insect species, and three species of insect pests, boisduval scale (*Diaspis boisduvalii* Signoret), smilax scale [*Melanaspis smilacis* (Comstock)] and Taiwan tussock moth [*Porthesia taiwana* (Shiraki)] were newly recorded on pineapple in Taiwan. By analyzing the pattern of spatial distribution of pink pineapple mealybug, results showed that it was an aggregative type of insect in the field. Its population mainly concentrated on the basal part of pineapple, and was positively correlated with the soluble solid contents on different parts of fruit. The control efficacy of three chemicals, namely, 50% Fenitrothion EC, 50% Fenthion EC and 40.8% Chlorpyrifos EC, that were recommended for pink pineapple mealybug in the earlier time remained effective in this study. These chemicals effectively controlled the insect on the 21th day after the second application. However, four non-synthetic chemicals adopted in this study, 2% coconut oil, 90% sunflower oil, 60% soybean oil and 99% mineral oil, had no effect on pest control.

Key words: Pineapple, Pink pineapple mealybug, Distribution, Control.

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小波羅蜜果實發育之研究

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摘要

李永民、劉碧鵑、顏昌瑞。2014。小波羅蜜果實發育之研究。台灣農業研究 63(1):77–83。

小波羅蜜 [*Artocarpus intege* (Thumb.) Merrill] 係台灣新興熱帶果樹，目前對果實發育生理與相關生產資料國內外發表的文獻均不多。本試驗旨在建立小波羅蜜果實發育基礎資料，調查不同生育階段的果實發育生理，了解其發育與成熟過程之變化。由試驗結果，果實的橫縱徑生長曲線為單 S 型，藉由果實生長率絕對生長速率 (absolute growth rate; AGR) 與相對生長速率 (relative growth rate; RGR) 發現果實發育曲線在花後 27、55 與 83 d 有顯著變化。經解剖小波羅蜜果實乃在花後 27 d 果皮與種子以發育，而花後 55 d 假種皮的發育，最後在花後 83 d 果實生長趨於和緩，至花後 104 d 果實開始軟化成熟。因此，推測小波羅蜜果實存在階段性生長，且相互影響各部位生長。

關鍵詞：小波羅蜜、絕對生長速率、相對生長速率。

前言

小波羅蜜 [*Artocarpus intege* (Thumb.) Merrill] 英名 Chempedak，屬桑科 (Moracea) 波羅蜜屬 (*Artocarpus*) 常綠熱帶果樹。小波羅蜜之果實較波羅蜜爲小 (1–3 kg)，果皮因無乳汁方便剝食，可作爲取代波羅蜜大果，較不利於小家庭消費的新興熱帶果樹 (Yen & Liou 2010)。小波羅蜜爲東南亞國家山區的原生果樹，雖有商業生產但未有品種選育與栽培技術改進的觀念，以至於目前國內外研究小波羅蜜的栽培文獻極少。小波羅蜜的生長習性與同屬的波羅蜜相似 (Kanzaki *et al*. 1997)，同爲多朵花組成的肉穗花序 (spadix)，每朵花均發育成爲一個小果，再聚合成聚花果 (collective fruits) (Chiang 1988)，其小果的發育將影響整個聚花果的發育。因此，本試驗將針對小波羅蜜果實發育進行研究，瞭解果實生長過程的變化與趨勢。

材料與方法

試驗材料

本試驗所使用材料爲印尼引進小波羅蜜的種子，共計培育 23 株，種植行株距爲 4 m × 1.5 m，栽植於國立屏東科技大學熱帶果園。經種植後 6 年開始產果，其植株高度約 3.5 m，樹冠寬度約 2 m，每株掛果 30 顆，平均果重約 1,200 g，且外觀圓整形沒有畸形。試驗調查時間包括 2010 年 8 月、2011 年 2 月及 2011 年 8 月三季果實。於試驗期間先給予牛糞堆肥 (有機質約 14.5%，氮約 0.4%，磷 0.2%，鉀 0.12%，比例 2 : 1 : 1；屏東科技大學畜產系生產由系上牛隻排泄製程) 與台肥 43 號混合肥料 (3：1)，共 3 次，每次約 2 kg。水分管理方面平均每週灌溉 1 次，每次噴灌約 20 min，並視天候狀況調節供水量。

試驗方法

果實發育規律研究：試驗 23 棵實生果樹，

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每棵果樹中逢機選取 15 個完整的雌花穗，待花穗授粉雌花穗柱頭萎凋後開始進行。試驗以卷尺測量各聚花果實縱徑 [果頂至果底最大距離，單位以公分 (cm) 表示] 與橫徑 [兩側果腹最大距離，單位以公分 (cm) 表示] 之變化。每 7 d 測量 1 次，直至花後 104 d 後果實開始軟化則停止測量，再以數值繪出小波羅蜜果實生長變化。(1) 果實生長曲線 (fruit growth curve)：測量之果實橫徑與縱徑變化爲縱軸，以發育時間爲橫軸，畫出生長曲線。(2) 果形指數 (fruit shape index)：果實縱徑/橫徑所得爲縱軸，以發育時間爲橫軸，畫出生長指數變化。(3) 絕對生長速率 (absolute growth rate; AGR)：單位時間內果實縱徑及果實橫徑之淨生長量。計算公式爲：h2 及 h1 爲測得的果實縱徑或果實橫徑，t2 及 t1 爲日數 : AGR = (h2 − h1)/(t2 − t1)。(4) 相對生長速率 (relative growth rate; RGR)：單位時間內果實果縱徑與果橫徑相對基數的增長百分率，計算公式：式中 h2 及 h1 爲測得的果實縱徑或果實橫徑，t2 及 t1 爲時間 : RGR = [(h2 − h1)/h1]/(t2 − t1) × 100%。

果實結構發育：試驗以編號 56-36 之小波羅蜜不易畸形果實爲範本，在花朵授粉後至果實軟化約 104 d，試驗每 3 d 調查一次外觀變化，內部構造於花後 20、27、55 與 83 d 進行果實解剖，觀測果皮、假種皮與種子間構造變化，以繪圖或相片紀錄 (相機 Nikon D5000)。

結果

小波羅蜜果實生長曲線

小波羅蜜果實縱徑與橫徑至花後 83 d 停滯生長，至花後 104 d 果實開始軟化成熟，其生長發育期間的縱、橫徑變化如圖 1 所示。果實的縱徑、橫徑生產動態呈「快速生長一緩慢生長」的「單 S 型」曲線變化 (圖 1A)。果實發育生長高峰爲自花後 20–27 d 開始，果實縱徑從 9.2 cm 增加至 10.6 cm，果實橫徑從 3 cm 增加至 3.8 cm；花後 27–83 d，果實縱徑從 10.6 cm 增加至 16.4 cm，果實橫徑從 3.8 cm 增加至 7.4 cm；末期花後 83 d 生育趨於緩慢，果實縱徑從 16.4 cm 增加至 20.7 cm，而橫徑則從 7.4 cm 增加至 12 cm。在果形指數的變化上 (圖 1B)，在花後 27、55、83、104 d，果形指數分別自 3.0、2.8 降爲 2.1、1.7，顯示果形從長橢圓形逐漸趨於橢圓形。

果實生長速率以絕對生長表示 (圖 1C)，果實縱徑生長爲花後 27、55 與 76 d，三點又以 55 d 的 49.3 cm d^{-1} 爲最高，顯示果實縱徑於 55 d 到達最高生長速率；果實橫徑生長於花後 20、48 與 76 d，其中以 48 d 的 30 cm d^{-1} 最高，顯示果實縱徑於 48 d 到達最高生長速率。相對生長 (圖 1D) 表示果實生長量，小波羅蜜果實縱徑生長爲花後 20、48 與 76 d，其中 20 d 生長達 22.7%，顯示果實縱徑生長主要於花後 20 d；果實橫徑生長爲花後 27、55 與 76 d，三點比較又以 27 d 爲生長高峰達 4%，顯示果實橫徑主要生長花後 27 d。

小波羅蜜果實結構發育

小波羅蜜果實解剖，內部有許多獨立小果，此構造與同屬的波羅蜜果實相似 (Ullah & Haque 2008)，其小果構造可分爲 3 層果皮層、果肉層及果心 (圖 2)。果皮層爲聚花果果皮，果皮成鱗棘狀，外層具臘質，對果實有良好的保護作用；果肉層爲小果，由外而內分別爲假種皮、外種皮及種子，假種皮與胚座連生；種子腎形，側生，有外種皮保護；胚位於種子腎形凹陷處；果心層爲複果果心，有固定果粒作用。

在果實生長曲線之主要發育時間花後 20、27、55 與 83 d 進行果實解剖，花後 20 d 果實外觀柱頭枯萎掉落，生長過程外果皮顏色漸漸轉淡 (圖 3)；房室膨大，授粉受精者明顯種子發育 (圖 4A)。花後 27 d 果實開始膨大，果皮外觀顏色漸漸轉黃，且鱗棘變大 (圖 3)；內部果皮與果肉層厚度比例相近，推測種子與果皮同時發育 (圖 4B)，造成果實迅速生長。花後 55 d 果實加快膨大 (圖 3)；假種皮由胚座兩側發育向兩側包覆，且種子增大 (圖 4C)。83 d 果實逐漸定型，果實明顯從鮮綠轉黃褐色，此時易受環境溫度變化影響果實成熟時間 (圖 3)，拍打果實時聲音較爲沈重，以指壓可感覺果實較前三期柔軟；果實內部空間加大，

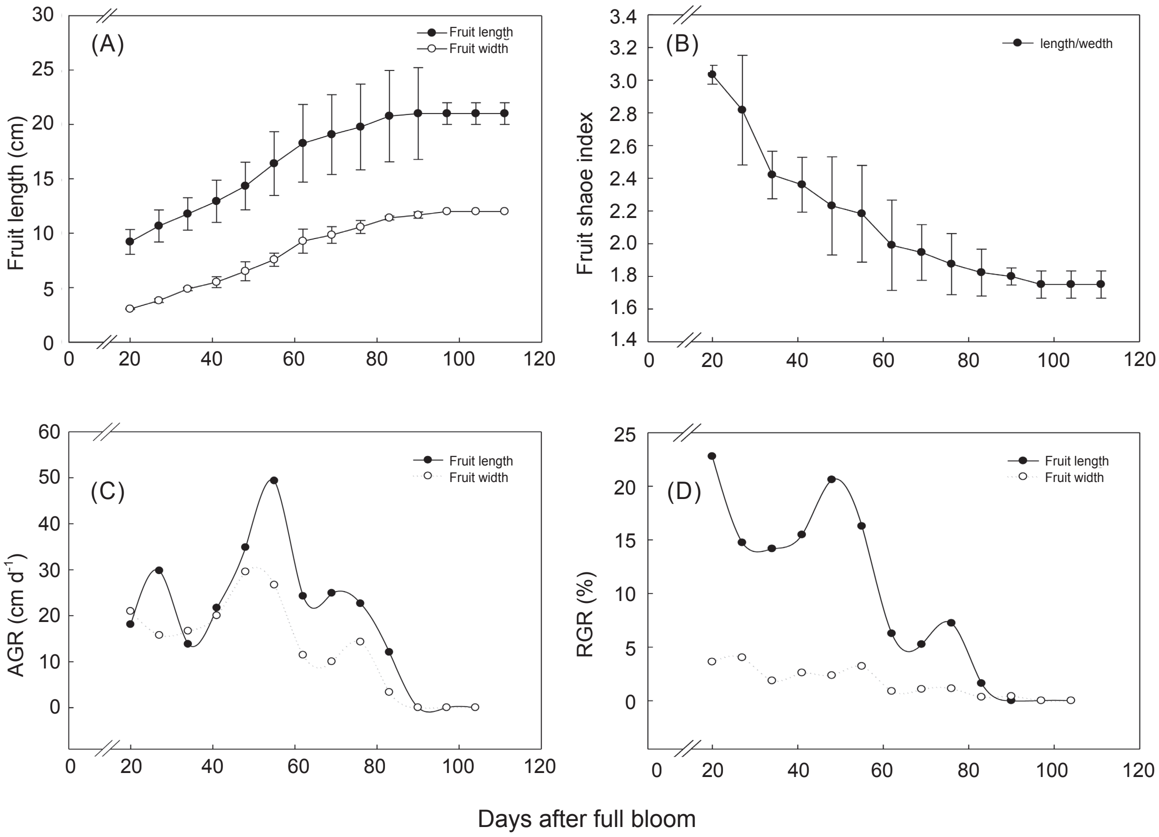

圖 1. 小波羅蜜果實生長曲線。(A) 果長和果寬；(B) 果形指數；(C) 絕對生長速率；(D) 相對生長速率。

Fig. 1. The developmental curve of chempedak fruit. (A) Fruit length and fruit width; (B) fruit shape index; (C) absolute growth rate (AGR); and (D) relative growth rate (RGR).

空隙變多，假種皮開始轉色，種子已成熟，果肉層較為鬆散 (圖 4D)。因此，綜合生長曲線變化，推測小波羅蜜果之小果發育於花後 20 d 種子開始發育，在花後 27 d 時種子與果皮會快速生長至 55 d；花後 55 d 假種皮開始發育，且種子仍繼續生長；果實發育於花後 83 d 假種皮與種子才逐漸停滯生長。

討論

果實的生長會因不同果樹種類或果實形態而有所差異，聚花果的研究中，鳳梨與無花果果實縱徑及果實橫徑的生長變化為單 S 型長曲線 (Cranc & Brown 1950; Yen *et al*. 1999)，而同為聚花果的小波羅蜜果實縱徑及果實橫徑的變化呈現單 S 型長曲線，與 Ullay & Haque (2008) 研究波羅蜜果實縱徑及果實橫徑生長曲線相似，因此推測小波羅蜜果實生長為 S 型長曲線；且小果發育影響果形變化，在無花果研究中，發現經過授粉使小果正常發育，能提升果實品質 (Hong & Chen 2003; Badii *et al*. 2011)，因此聚花果的生長變化受小果發育影響。

植物體在生長發育過程，器官間、組織間或細胞間，都具有生長相關性 (growth correlation) 相互影響著 (Meyer *et al*. 1973)，小波羅蜜果實發育解剖試驗發現花後 20 d 種子與果皮以發育，而花後 55 d 發現假種皮發育，由 AGR 曲線發現花後 55 d 為最大生長量，而 RGR 曲線發現生長量花後 27 d 最高日後驅緩。推測果實發育初期為種子與果皮生長日漸區減緩，在花後 55 d 轉為假種皮發育，此時假種皮發育空間受果皮發育空間影響。Huang

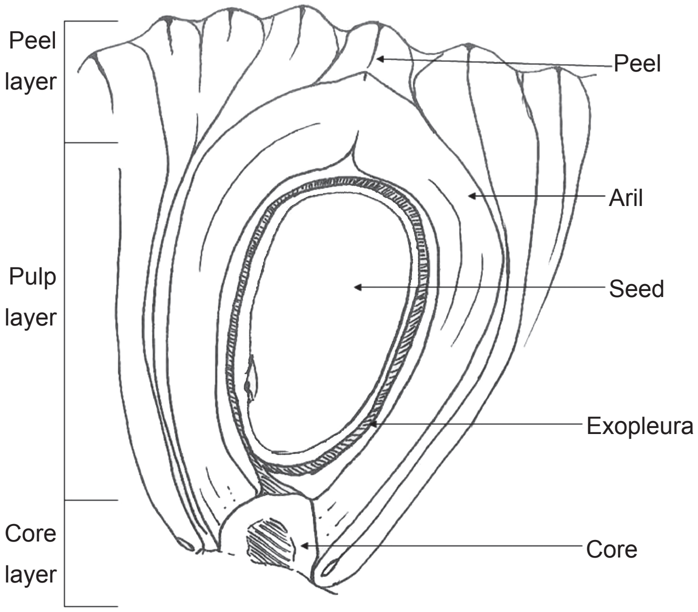

圖 2. 小波羅蜜小果縱解剖圖。

Fig. 2. Longitudinal section of chempedak small fruit.

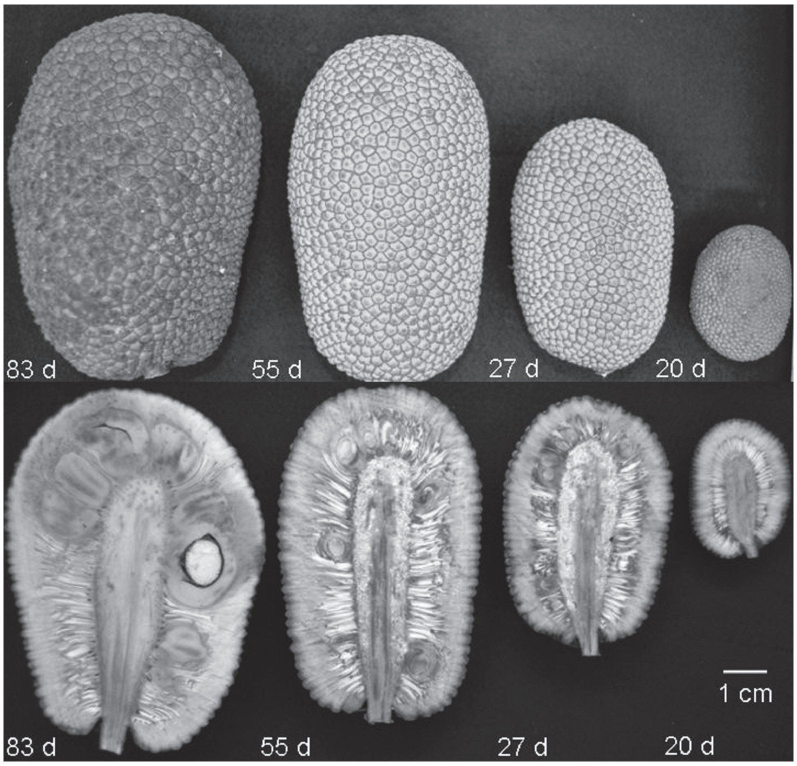

圖 3. 小波羅蜜果實發育過程外觀與縱剖面之變化。

Fig. 3. Overall appearance and longitudinal section during chempedak fruit development.

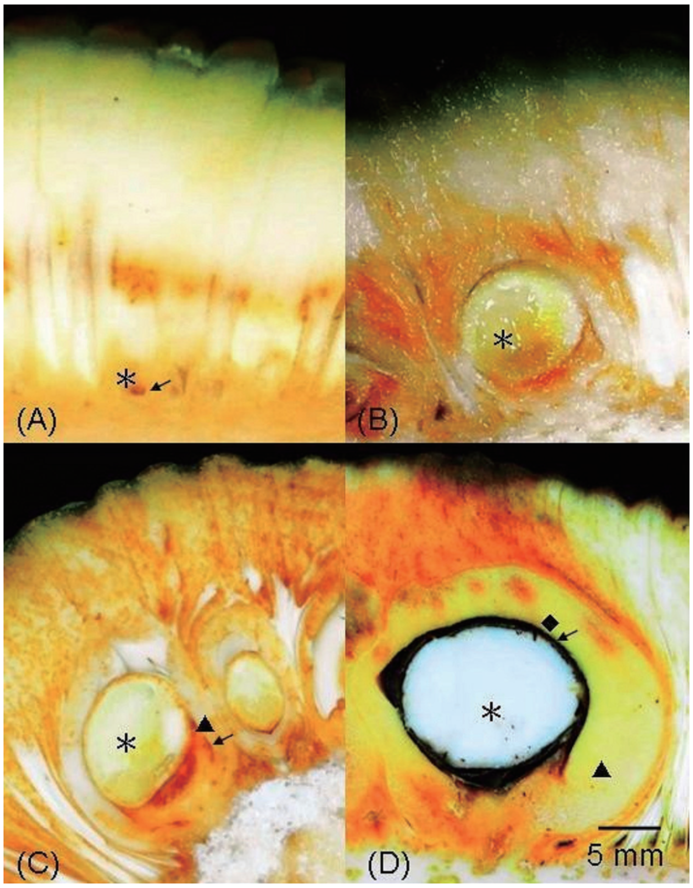

圖 4. 小波羅蜜果實發育解剖圖。(A) 20–27 d，箭頭指示為種子；(B) 27–55 d，種子膨大；(C) 55–83 d，箭頭指示為假種皮；(D) 83–104 d，箭頭指示為外種皮，且子葉轉色，種子已成熟。＊：種子；▲：假種皮；◆：外種皮。

Fig. 4. Fruit anatomy during development of chempedak fruit . (A) 20–27 d, arrow indicates seed; (B) 27–55 d, enlarged seed; (C) 55–83 d, arrow indicates aril; (D) 83–104 d, arrow indicates exopleura; color of cotyledon changed and seed matured. ＊ : seed; ▲ : aril; ◆ : exopleura.

& Xu (1983) 荔枝研究指出荔枝果實構造生長順序為果皮與種子、假種皮，果皮空間將限制假種皮的生長，果實構造生長程序相同，因此推測果皮與種子的發育將影響果形。在 Liou (2010) 小波羅蜜的研究中，指出「焦核」品種種子敗育，小果發育不佳，造成聚花果外觀畸形。植物生理中種子敗育，仍然可促使果實發育，Qiu & Huang (1986) 指出荔枝果皮與種子生長是同步生長組織，所以正常種子者果皮較敗育者果皮大，由此推測小波羅蜜種子發育會影響果實畸形。

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Study on Fruit Development of Chempedak [*Artocarpus integer* (Thumb.) Merrill]

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Abstract

Li, Y. M., P. C. Liou, and C. R. Yen. 2014. Study on fruit development of chempedak [Artocarpus integer (Thumb.) Merrill]. J. Taiwan Agric. Res. 63(1):77–83.

Chempedak (*Artocarpus chempeden*) is a newly emerging fruit crop in Taiwan. However, few reports are available about its cultivation and production in Taiwan. In this study, results revealed that fruit development of Chempedak displayed a sigmoid fashion. By analyzing absolute growth rate (AGR) and relative growth rate (RGR) during fruit development period, it was evident that fruit development curve changed significantly at 27, 55 and 83 days after flowering (DAF). Seed and peel appeared at 27 DAF, aril emerged at 55 DAF, and no significant anatomical changes in chempedak fruit at 83 DAF. Fruit were mature and soften for harvest at 104 DAF. Accordingly, results suggest that there exist differences in developmental stages during fruit growth which interact each other along the development.

Key words: Chempedak, Absolute growth rate, Relative growth rate.

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台灣農業研究 (J. Taiwan Agric. Res.) 63(1):84–90 (2014)
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糧食生產評估系統之建置：以水稻生產為例

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摘要

陳俊仁、姚銘輝、陳宣蘋、廖芳瑾。2014。糧食生產評估系統之建置。台灣農業研究 63(1):84–90。

本研究目的旨在建立適用於我國之糧食生產評估系統，同時以水稻生產為例進行產量模擬與驗證。整合氣象、作物及土壤等資料庫利用 DSSAT 模式進行水稻產量模擬，並建立模式驗證機制以確認系統具有評估能力。模擬結果則以地理資訊系統進行面化，依據 5 km × 5 km 網格估算值，評估不同農業政策調整下整體水稻生產力，提供氣候變遷因應措施及農田活化等政策之依據。

關鍵詞：水稻、作物模式、地理資訊系統、氣候變遷。

前言

氣候變遷影響全球農業生產，包括影響我國糧食生產量及國外進口量，國外進口量，隨著自然災害的增加，可預期未來糧食生產量將減少，導致價格將持續飆漲，未來可能產生有錢也買不到糧食的情況，因此如何調整農業耕作方式及提高糧食自給率，以維護我國糧食安全是重要議題。Huang *et al*. (2008) 指出台灣農產業面臨諸多問題，包括糧食自給率偏低、農民年齡老化、大面積農地休耕、耕地規模小、肥料價格高漲、氣候變遷造成自然災害增加及世界糧食經濟的快速轉變等，這些因素將影響我國未來糧食的穩定供給。誠然，評估我國糧食生產潛力係作爲糧食政策調整及氣候變遷因應調適策略的基礎，尤其亟待建立國家尺度之糧食生產評估系統。本研究所研發之糧食生產評估系統 (圖 1)，具有整合現有氣象、作物及土壤資料庫，利用作物模式評估作物生產力，並結合地理資訊系統以網格化形式呈現，以建置具有評估我國整體糧食生產力系統之評估能力。

農業生產力受許多因素影響，因此評估農業生產力必須全方面的考量，利用作物模式進行產量模擬，來評估農業生產力爲常見的方法之一 (Tao *et al*. 2009; Osborne *et al*. 2013)。作物模式利用電腦以數學方式描述作物真實生長、發育及產量，當然作物模式無法涵蓋所有環境和作物間之交感，同時許多相關性是以假設性爲前提，且亦非線性。Ritchie (1994) 認爲作物模式有三種類型，一種爲統計型模式，此種模式是由最後產量資料和區域平均天氣變數作回歸，因此這類模式僅具區域代表性，適用範圍狹窄；第二型爲機制型模式，乃以數學敘述大多數作物生長及發育的過程，一般用於研究用途，因生物特性複雜，而且與環境的交感尚未完全釐清，僅由數理公式作推演有其侷限性，對於田間作物預測較不實際；第三型屬於功能型模式，以數理方程式結合田間作物經驗值用以預測複雜的作物生長過程以及和大氣、土壤環境間的交感。

目前常用的作物模式大多屬於功能型模式，包括 DSSAT (Jones *et al*. 2003)、APSIM

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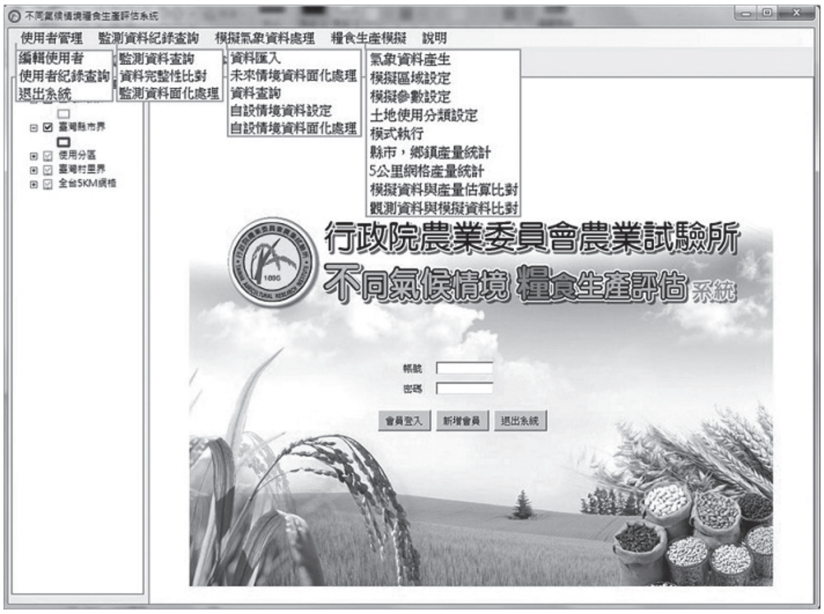

圖 1. 不同氣候情境糧食生產評估系統之畫面及功能表。

Fig. 1. The homepage and menu of the evaluation grain food production under different climate scenarios.

(McCown *et al.* 1996)、CENTURY (Parton 1996)、ORYZA 2000 (Bannayan *et al.* 2005)、EPIC (Tan & Shibasaki 2003)、STIC (Brisson *et al.* 2003) 和 DNDC (Li 2000) 等。每一種模式皆有其特殊運用目標，如 ORYZA 2000 以模擬水稻生育為主，包括 ORYZA1 (評估潛能產量)、ORYZA-W (限水生產) 及 ORYZA-N (限氮肥生產)，對於其他作物則無評估能力。EPIC 具備作物生長評估能力，特別著重於土壤沖蝕、土壤生產力及不同農田地貌管理。CENTURY 則強調在作物土壤間之營養分循環、土壤水分收支平衡及土壤有機物分解模式等。DNDC 具有評估農田溫室氣體排放估算的功能。STIC 並非為固定作物模式，而是一種作為其他模式交流的平台。APSIM 與 DSSAT 模式相近，但缺少水稻的模擬功能。

現今作物模式有許多種，其中運用最廣泛為 DSSAT 模式 (White *et al.* 2011)。該模式用於模擬均一田區作物之生長、發育、產量及土壤水分、碳及氮的變化 (Jones *et al.* 2003)，DSSAT 自 1993 年發展至今可模擬 37 種主要農作物，包括水稻、玉米、大豆、小麥及其他作物，模擬作物種類雖多，但共用土壤-作物-大氣交感之模組。本研究所用作物模式為 DSSAT 4.5 版為綜合性模式，其所需參數甚多，包括耕地土壤特性 (質地、酸鹼度、離子含量及有機質含量等)、作物特性 (遺傳特性及生理特性) 及氣象資料。DSSAT 氣象資料輸入值為每日之最高溫度、最低溫度、日射量及日累積降雨量，施用氮肥量設定為 113 kg N ha^{-1}，模擬過程中設定為無肥料及水分逆境。本研究室過去曾利用 DSSAT 3.0 版建立「台農 67 號」及「台中秈 10 號」兩品種之遺傳參數 (Yao *et al.* 2000)，由於新版仍沿用舊版之評估方式，因此本研究仍採用已建立之稻種遺傳參數。

材料與方法

模式開發與模擬

本研究糧食生產評估系統之開發，係採用 Visual Studio 2010 程式 C# 語言，空間資料運算採用 ESRI ArcGIS Engine 10 以上版本開發獨立運作系統。將各氣象測站之實測及模擬資料以地理資訊系統 (geographic information system; GIS) 技術進行面化，並將面化之圖資屬性資料存入資料庫。開發之糧食評估介面直

接執行 DSSAT 模式模擬功能，模擬結果之單位面積產量可和已存於資料庫中之農委會農糧署之歷年水稻坪割資料作比對。另由國土測繪中心提供之土地使用分類資料，條列各鄉鎮水稻種植面積，再由預估單位面積產量乘以種植面積得到鄉鎮總產量，累加後即可得全國水稻產量。模擬後產量值以 5 km × 5 km 網格之 GIS 地圖方式呈現。氣象資料除現有完整觀測資料外，也預留可擴增未來氣候變遷下不同氣候情境之模擬資料，未來可依據不同氣候情境評估糧食生產量。

模式氣象資料建立

系統研發是以水稻生產區之產量面化爲目標，而水稻生產受氣象影響，因此需要詳細氣象資料，而我國中央氣象局氣象觀測網能提供 DSSAT 作物模式所需氣象資料，包括日最高溫、日最低溫、日射量及日累降雨量等氣象因子觀測值之測站共 67 站，各測站均爲局屬氣象站。在進行 DSSAT 模式預測結果之資料平面化工作時，爲使測站在空間分佈上具有代表性，少數測站之日射量缺值部分，則由日照時數及溫度差所建立之回歸方程式推估 (Chen *et al*. 1994; Yao *et al*. 2002)。本研究氣象資料年份取自 2006–2010 年共 5 年的資料，同時將台灣劃分爲 1,568 個 5 km × 5 km 的網格 (圖 2)，先進行 67 個測站之氣象資料完整性 (係指單一年度有紀錄之氣象天數占總天數之百分比) 分析，當完整性低於 90% 則不採用，因此實際可用的測站約 45–50 個之間。將選取之測站的單一氣象因子資料進行單一年度逐日資料內插面化工作，四種氣象因子每年將產生 1,460 張逐日氣象面化圖，再以網格爲單位，將內插後之網格氣象資料輸入 DSSAT 模式內，即可產生水稻產量網格圖。其中，海拔高度超過 500 m 以上不納入計算，因爲超過此高度水稻種植極少。

水稻生育與氣象因子之分析

爲瞭解水稻生育與氣象因子之關係，實測驗證資料有兩個來源，其一爲農委會農業試驗所進行之水稻豐歉試驗，自 1993 年一期作至 2012 年二期作止共 20 年，合計 40 個期作資料。生育資料是由插秧後 3 週開始調查，包括每週調查葉乾重、桿乾重、穗重、葉面積，並於成熟期調查產量及產量構成要素。由於試驗目的在分別探討四種氣象因子和產量間的關係 (表 1)，因此分別利用 20 期的一期或二期水稻產量變化與四種氣象因子變化趨勢，進行相關

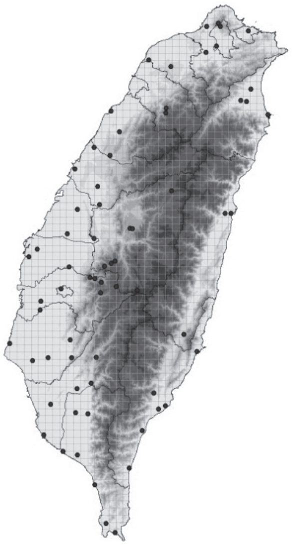

圖 2.　DSSAT 模式所用氣象測站空間分布及台灣地區 5 km × 5 km 網格。

Fig. 2.　Spatial distribution of weather stations for DSSAT model and 5 km × 5 km mesh in Taiwan area.

分析。由於水稻試區是在固定田區，由專人負責作一致的管理，並適度控制病蟲害發生，因此可盡量排除非氣象的影響因子，並以農委會農糧署所提供的 2006–2010 年鄉鎮水稻坪割調查資料作為區域水稻產量驗證資料的來源。

結果與討論

模擬值的驗證結果

由糧食評估系統所模擬之我國西南部 (大台中市至屏東縣) 水稻一、二期產量如圖 3，一期作產量顯然高於二期作，這和一期作生育日數較長有關。當然，模擬結果需驗證與實測值的差異。圖 4 為我國西南部水稻栽培面積大於 1,000 ha 之鄉鎮共 55 個，以近 5 年 (2006–2010 年) 坪割水稻產量與模擬結果以座標顯示。兩者呈現一定程度的相關性，經進行 F 檢定，結果顯示 F 值 (= 0.782677) 小於臨界值 (= 0.819481)；另由直接檢視 P (F ≦ f) = 0.0255 > 0.025 結果，顯示接受兩變方相等的虛無擬說，即觀測值與模擬值兩組資料變異性大小沒有差異 (圖 4)。若經由平均絕對值誤

表 1.　水稻二期作之平均生質量與氣象因子之相關性。

Table 1. Correlation coefficients between the mean biomass of rice (*Oryza sativa* L.) and meteorological factors recorded at trial site of Taiwan Agricultural Research Institute during two cropping seasons in 1993–2012.

Cropping season	Mean biomass ($g\ pl^{-1}$)	Tmax (℃)	Tmin (℃)	Solar radiation ($MJ\ season^{-1}$)	Precipitation ($mm\ season^{-1}$)
1^{st} crop	63.92	-0.10	-0.28	0.69^{**}	-0.08
2^{nd} crop	54.15	0.22	0.01	0.46^{**}	-0.39^{*}

*, **Significant at the 0.05 and 0.01 probability levels according to the correlation analysis.

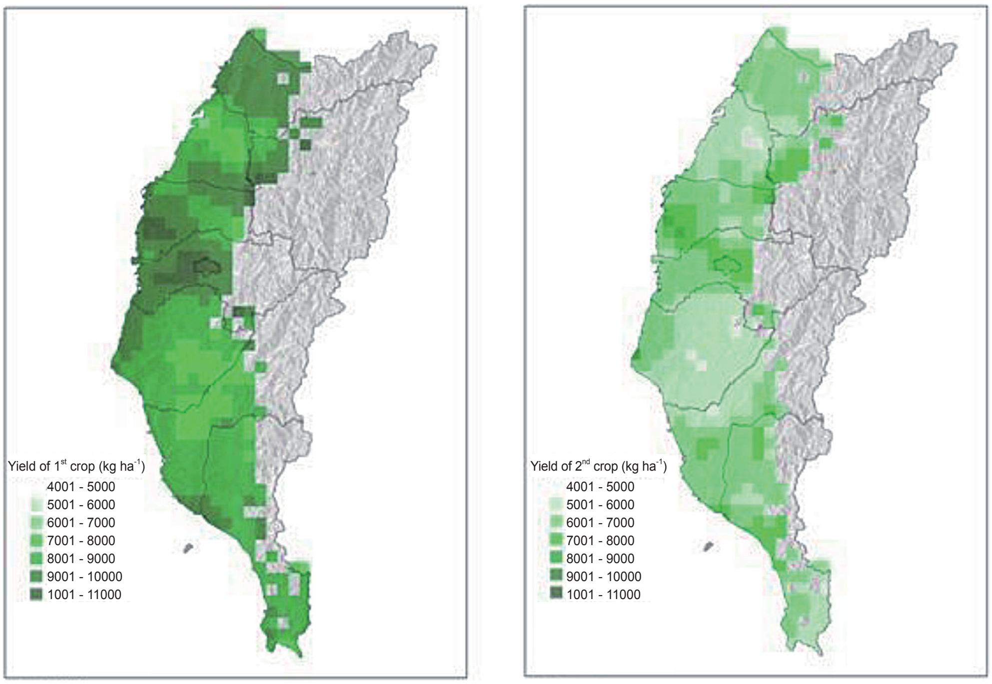

圖 3.　台灣西南部水稻一、二期水稻模擬產量。

Fig. 3.　Simulated rice grain yield of first and second crop seasons of west-south area in Taiwan.

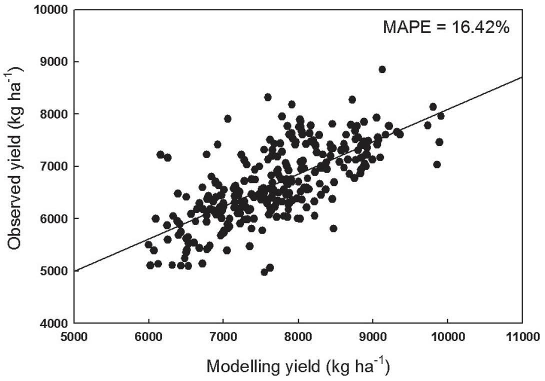

圖 4. 水稻實測產量與 DSSAT 模擬產量之相關性。圓點代表水稻種植面積大於 1,000 公頃之鄉鎮。

Fig. 4. The relationship between observed rice yield and simulated by the DSSAT model. Each point was represented the village of paddy rice cultivation area ≧ 1,000 ha.

差率 (mean absolute percentage error; MAPE) 作為預測模式好壞之評估指標，使能夠客觀獲得模擬值與實測值之間的差異程度，由結果可知 MAPE = 16.42%，屬於優良的預測 (MAPE = 10–20%)。由於 DSSAT 模擬出的產量大多會較實際坪割產量為高，主要是在 DSSAT 模式設定為無肥料、水分逆境及病蟲害發生，而就實際現況而言，取得每一鄉鎮水稻栽培條件及生長狀態的詳細資料並不可行。由過去 5 年坪割實測資料，年際間產量變異約在 ± 1,000 kg，而大部分鄉鎮之模擬與實測產量之差值大多落在此範圍內，因此本系統之產量模擬結果仍屬可接受。

另就產量空間分布而言，在雲林縣及嘉義縣有水稻高產區，而屏東縣及高雄市水稻產量相對的低，顯示 DSSAT 可以反應出產量在空間上的變化。本系統研發目的不僅限於估算產量，由空間上產量的差異作為未來適栽區的規劃也是目標之一。我國未來糧食作物生產將受極端天氣影響，以水稻生育而言，苗期遭受低溫害，開花期高溫害及成熟期因風雨害之倒伏，對產量皆有明顯影響。由農業氣象觀點，適栽區應選擇遭受災害受損較少之地區生產，才能確保穩定糧食生產，由本系統所估算之空間區域產量可作為這方面研究的基礎。

在產量模擬及驗證過程中，各個資料庫的完整性皆有需要加強的部分，包括氣象、作物及土壤資料庫皆然。舉例而言，表 1 是整理農業試驗所進行 20 年之水稻豐歉試驗及氣象資料的結果，可發現一期作水稻乾物重產量和日射量相關係數達 0.69，其餘因子不顯著；二期作日射量與水稻乾物重之相關係數仍達顯著水準，另累積雨量與乾物重呈負相關。綜合來說，顯然 DSSAT 所需氣象因子中以日射量最為重要。Jong *et al*. (1982) 研究指出夏威夷所種植玉米可由日射量解釋 78.5% 產量的變異，說明了日射量變化是作物生長的主要變異來源。由區域或全國性產量預測角度而言，國內現行的日射量資料在觀測點數及地域分佈並不足夠，以 2010 年為例，全國共有 1,117 個氣象站分佈於各地，其中雨量測站相當密集，而具有最高溫度及最低溫度之測站也有 180 個，但有日射量資料之測站僅 67 個，扣除高山及離島，分布在農業區的測站則寥寥可數。因此，在增進區域氣象預測能力及糧食產量預估準確性的前提下，具有日射量觀測項目之氣象測站不足將是一大隱憂。

本研究室曾進行氣候變遷衝擊下水稻生產影響評估之研究 (Yao *et al*. 2000; Yao & Chen 2009)，近年來國際上針對未來氣候之預測能力已有大幅度進展，同時作物模式也隨著對作物生理的瞭解而不斷的版本升級，對於作物生長及產量具有更佳的描述及預測功能，所評估之空間尺度亦逐漸加大，對於全國性的作物產量預測有更佳的準確性。DSSAT 模式過去以單一作物個別分析方式模擬產量，近年也發展田區不同作物之產量面化分析模組 (Thorp *et al*. 2008)，產量預估值之輸出檔案可與地理資訊系統之 ArcGIS 連結，自動產生面化之分析結果，可評估區域內之不同作物之整體生產力。但因 DSSAT 內建 GIS 版本過久且操作不易，此外，系統氣候資料匯入功能不易，每一筆模擬資料需人工操作，面對大量氣象資料須耗費極多時間。因此，本系統即為研發自動模擬系統並結合新版 GIS 軟體，整合各項參數之資料庫，由參數選定、敏感度分析、模擬產量及面化出圖等，建立一貫化運算流程，將可有效縮短評估時間。

我國過去對於農作物生產的評估及預測研究相當有限，且多僅限於資料調查及個案性推估研究，缺乏整體性研究，不利於擬訂整體農業政策評估及氣候變遷因應策略之科學基礎。評估國家糧食安全性可由脆弱度 (vulnerability) 及回復力 (resilience) 之優先次序的觀念，擬定各項調適策略以因應氣候變遷的衝擊。本系統研發目的即在整合現有資料庫，利用作物模式進行整體糧食生產的估算，經與實測資料比較結果 (圖 3 及圖 4)，系統能掌握水稻產量的變化，未來將針對其他糧食作物進行生產潛力之評估，期以有助於各項農地政策調整及氣候變遷因應策略之用。

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Establishing an Evaluation System for Food Production: A Case Study on Rice Production

Chun-Jen Chen[1], Ming-Hwi Yao[2,*], Hsuan-Ping Chen[3], and Fang-Ching Liao[3]

Abstract

Chen, C. J., M. H. Yao, H. P. Chen, and F. C. Liao. 2014. Establishing an evaluation system for food production: A case study on rice production J. Taiwan Agric. Res. 63(1):84–90.

The purpose of this study was to setup an evaluation system for grain crop production in Taiwan. Take paddy rice production as an example, the system adopted DSSAT model and used weather, crops and soil databases for model simulation. The simulated outputs were used to evaluate the entire regional paddy rice productivity based on a 5 km × 5 km coordinate system with the aid of geography information system (GIS). The verification system to validate simulation outputs was also established. By using the evaluation system with various environmental conditions, it would provide valuable information for strategy planning to cope with climate change as well as to activate the reuse of fallow land.

Key words: Rice (*Oryza sativa* L.), Crop model, Geography information system (GIS), Climate change.

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